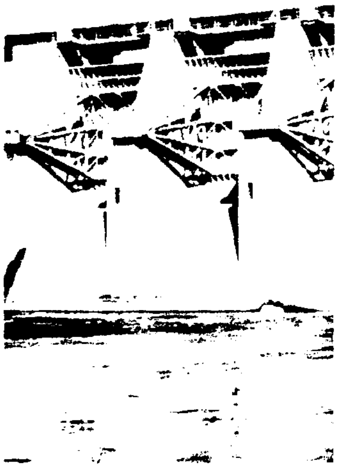
US Army Corps of Engineers



TECHNICAL REPORT EL-90-5

PREDICTED WATER QUALITY IMPACTS OF IMPOUNDMENTS ON THE ROGUE RIVER, OREGON

by

Dorothy E. Hamlin-Tillman

Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

and

Carla Haake

US Army Engineer District, Portland
Portland, Oregon 97208-2946

May 1990

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for US Army Engineer District, Portland
Portland, Oregon 97208-2946

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Technical Report EL-90-5	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION See reverse. — 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) See reverse.	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION USAED, Portland — 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Portland, OR 97208-2946	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Predicted Water Quality Impacts of Impoundments on the Rogue River, Oregon

12. PERSONAL AUTHOR(S)
Hamlin-Tillman, Dorothy E.; Haake, Carla

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final report	FROM ______ TO ______	May 1990	122

16. SUPPLEMENTARY NOTATION
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	See reverse.

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report documents efforts to evaluate the cumulative impacts of operation of Lost Creek, Applegate, and Elk Creek Dams on water temperature and turbidity in the Rogue River, Oregon. The modified version of the US Environmental Protection Agency's one-dimensional riverine water quality model, QUAL II, was used as a predictive tool to assess impacts of all projects on downstream temperatures and turbidity. Application of the US Army Engineer Waterways Experiment Station model CE-THERM-R1 to Lost Creek lake for a dry, wet, and average water year is also presented in this report.

Other topics addressed are data requirements for CE-THERM-R1 and QUAL II, results of calibration/verification for both models, and results and conclusions from the five scenarios simulated with QUAL II.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code) — 22c. OFFICE SYMBOL

6. NAME AND ADDRESS OF PERFORMING ORGANIZATION (Continued).

USAEWES, Environmental Laboratory
3909 Halls Ferry Road, Vicksburg, MS 39180-6199;
USAED, Portland
Portland, OR 97208-2946

18. SUBJECT TERMS (Continued).

Applegate Dam	Model calibration/verification
Applegate River	Rogue River
Elk Creek Dam	Temperature and suspended sediment simulations
Lost Creek Dam	Turbidity

PREFACE

This report was prepared within the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. The study was sponsored by the US Army Engineer District (USAED), Portland, Portland, OR.

This study was conducted and the report was prepared by Ms. Dorothy E. Hamlin-Tillman of the Water Quality Modeling Group (WQMG), Ecosystem Research and Simulation Division (ERSD), EL, WES, and Ms. Carla Haake of the USAED, Portland. This report was prepared under the direct supervision of Mr. Mark S. Dortch, Chief, WQMG, and under the general supervision of Mr. Donald L. Robey. Chief, ERSD, and Dr. John Harrison, Chief, EL.

The technical reviews of Mr. Thomas M. Cole and Dr. John M. Nestler, both of the WQMG, are gratefully acknowledged.

Commander and Director of WES was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

This report should be cited as follows:

Hamlin-Tillman, Dorothy E., and Haake, Carla. 1990. "Predicted Water Quality Impacts of Impoundments on the Rogue River, Oregon," Technical Report EL-90- , US Army Engineer Waterways Experiment Station, Vicksburg, MS.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
acre-feet	1,233.489	cubic meters
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
inches	2.54	centimeters
miles (US statute)	1.609347	kilometers
square miles	2.589998	square kilometers

PREDICTED WATER QUALITY IMPACTS OF IMPOUNDMENTS ON THE ROGUE RIVER, OREGON

PART I: INTRODUCTION

Background

1. Elk Creek Lake is a multipurpose storage project located on Elk Creek, 1.7 miles* upstream of the junction with the Rogue River (Figure 1). Along with Lost Creek Dam and Applegate Dam, Elk Creek Dam was authorized by Congress in 1962 for the Rogue River Basin Project. The primary authorized project purpose is flood control, with secondary project purposes of fish and wildlife enhancement, municipal and industrial water supply, irrigation, and recreation. Elk Creek Lake is located approximately 30 miles northeast of Medford, OR.

2. Construction of Elk Creek Dam began in February 1986 and was halted in January 1988. The US District Court, under the direction of the Ninth Circuit Court, issued an order in September 1987 enjoining construction of the dam when it reached a height of 83 ft, one third of its design height. The Ninth Circuit Court ordered construction halted after finding that the 1980 Environmental Impact Statement Supplement No. 1 (US Army Engineer District (USAED), Portland 1981) was deficient for four reasons. Briefly:

   a. It did not contain a detailed analysis of wildlife mitigation measures.

   b. New information regarding the environmental impact of the project was not addressed in a new supplement.

   c. The cumulative impacts of Elk Creek Lake were not adequately addressed in conjunction with Lost Creek and Applegate Lakes.

   d. A worst-case analysis of Elk Creek's impact on the Rogue River was not included.

3. Three of the four issues were appealed to the Supreme Court, which overturned all three judgments in favor of the Corps of Engineers. The cumulative impact issue was not appealed. The Portland District was required

---

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.

to conduct a water quality study to address the issue of cumulative impacts as directed by the Federal Ninth Circuit Court of Appeals.

Study Objective

4. The Environmental Laboratory of the US Army Engineer Waterways Experiment Station (WES) was requested to assist the Portland District in the numerical modeling of a number of water quality constituents in the Rogue River Basin. Model results would be used to evaluate the cumulative impacts of operating the three multipurpose projects--Lost Creek, Applegate, and Elk Creek--in the Rogue Basin.

5. The main water quality constituents of concern in the Rogue River were water temperature and turbidity. However, turbidity could not be simulated directly for two reasons. First, turbidity is a measure of how much a beam of light is scattered or absorbed by material held in suspension in water. Therefore, it is an optical property and not a measure of mass. A basic assumption of the computer analyses is that mass would be conserved. A study by Larson, Wooldridge, and Wald (1976) showed that turbidity does not behave in a conservative manner when diluted. Second, because of equipment problems at most turbidity monitoring stations in the Rogue River Basin, high runoff data critical to the turbidity analyses were usually missing. Given these difficulties, it was decided that suspended sediment, which is a measure of mass, should be used in the computer simulations and the model output converted to turbidity.

6. Five scenarios were evaluated for a 10-year study period (1978-1987) to determine the cumulative impacts of all projects on Rogue River water temperature, suspended sediments, and turbidity. These were:

a. Conditions before any dams were constructed.

b. Conditions with only Lost Creek operating.

c. Conditions with only Lost Creek and Applegate operating.

d. Conditions with Lost Creek, Applegate, and Elk Creek operating at full conservation pool.

e. Conditions with Lost Creek, Applegate, and Elk Creek operating at minimum flood control pool.

General Modeling Approach

7. Two numerical models were required by the Environmental Laboratory to complete this study. First, as a combined effort of the WES Hydraulics Laboratory and Environmental Laboratory, the one-dimensional reservoir models WESTEX and CE-THERM-R1 were applied to Lost Creek Lake for a dry, wet, and normal water year (1981, 1984, and 1986, respectively). Results from the CE-THERM-R1 (Environmental Laboratory 1982) simulations were used to verify the WESTEX model (Hydraulics Labo· .tory). The WESTEX model was used to generate all project releases based on the most recent target temperatures.

8. After WESTEX had generated all project release constituents, these were used as headwater boundary conditions in the riverine modeling effort. For the riverine modeling effort, a modified version of the US Environmental Protection Agency (USEPA) one-dimensional (longitudinal) riverine model, QUAL II, was implemented t assess the effects of operating the three multi-purpose projects, Lost Creek, Elk Creek, and Applegate, on downstream water temperatures, suspended sediments, and turbidity in the Rogue River.

Site Description

9. The Rogue River originates in the Cascade mountains northwest of Crater Lake and flows south and west 210 miles to the Pacific Ocean at Gold Beach, OR. The portion (Figure 1) of the Rogue River chosen for the simulations begins at the US Geological Survey (USGS) gaging station "below Prospect," at river mile (RM) 169.4 and extends downstream to Marial, OR (RM 49). Within this study reach, a number of significant water resource features occur. Two are the existing Corp projects--Lost Creek Dam on the upper Rogue River and Applegate Dam (RM 56) on the Applegate River, a major tributary of the Rogue River at RM 94.5.

10. Lost Creek Dam has a drainage area of 674 square miles (13 percent of the total area of the Rogue River Basin) and a storage capacity of 465,000 acre-feet. It is currently operated to provide a minimum release flow of 700 cfs. In comparison, the Applegate Dam has a drainage area of 223 square miles (4.5 percent of total basin drainage area), a storage capacity of 82,000 acre-feet, and is operated to provide a minimum release flow of 100 cfs. Both dams are operated for flood control, fish protection

and enhancement, and recreation. Lost Creek Dam is operated for hydropower production.

11. A third dam, Elk Creek Dam (RM 1.7), is under construction on Elk Creek, a tributary of the upper Rogue River at RM 152. It has a drainage area of 133 square miles (3 percent of total basin drainage area) with a storage capacity of 110,000 acre-feet. Elk Creek Dam is proposed to have a minimum release flow of 30 cfs. This new project will be operated for flood control, irrigation, fish and wildlife enhancement, water supply, recreation, and water quality control.

12. In general, the Rogue River is a meandering, steep-sloped channel with the upper reaches usually wider than the lower reaches. There are many deep pools in the narrow reaches (i.e. between Grants Pass (RM 101.8) and Gold Hill (RM 120)) where depths greater than 30 ft have been sounded during periods of low flow (Harris 1970). Two run-of-the-river dams, Raygold (RM 125.4) and Savage Rapids (RM 107.5), occur between Bear Creek (RM 126) and Grants Pass.

13. The climate for the study reach is characterized by mild, wet winters and hot, dry summers. The nearest first-order weather station to the study site, at Medford, OR (elevation 1,290 msl), has a monthly average temperature range from 3.0° C in January to 22.2° C in July and an annual precipitation of 19.78 in. (USAED, Portland 1974).

14. The streamflow regime of the Rogue River and tributaries reflects the regional precipitation pattern. During the June through October period, low flows prevail; during the rest of the year, intermediate to high flows usually occur. These flows can fluctuate widely depending upon synoptic meteorological conditions and snowmelt. The topography and geology of the Rogue River Basin cause rapid runoff, resulting in peak flows within hours after a rainstorm. The average annual runoff of the Rogue River below South Fork Rogue River (basin area, 650 square miles) near Prospect, OR (near the headwaters of Lost Creek Lake), for the period 1929 to 1972 is approximately 1,780 cfs or about 1,300,000 acre-feet per year (USAED, Portland 1974).

Report Organization

15. A number of tasks were required to complete the reservoir and riverine modeling efforts. An overview of the report organization is given below, describing the tasks necessary for the modeling efforts.

Modeling approach for CE-THERM-R1

16. Part II identifies the criteria used to select CE-THERM-R1 for modeling Lost Creek Lake water temperatures and suspended sediments, describes the strengths and limitations of CE-THERM-R1, describes the operation of CE-THERM-R1, and lists assumptions made in modeling.

Data requirements for CE-THERM-R1

17. Part III identifies and describes the observed data sources used in the study. It also identifies methods for synthesizing missing or unavailable data.

CE-THERM-R1 calibration/verification

18. Part IV discusses steps involved in calibration/verification of CE-THERM-R1 for Lost Creek Lake. Results of calibration/verification runs are also presented and discussed.

Modeling approach for QUAL II

19. Part V identifies the criteria used in selecting QUAL II for modeling of Rogue River water temperatures and suspended sediments, describes the strengths and limitations of QUAL II, describes the operation of QUAL II, presents modifications made to the code to increase its utility for this application, and lists assumptions made in the study.

Data requirements for QUAL II

20. Part VI identifies and describes the observed data sources used in this study. It also identifies methods used to synthesize missing or unavailable data.

QUAL II calibration/verification

21. Part VII discusses steps involved in hydraulic and constituent calibration/verification of QUAL II for the Rogue River system. Also, the results of calibration/verification runs are presented and discussed.

Results from QUAL II scenarios

22. Part VIII presents the results for the 10-year simulation period of water temperature, suspended sediments, and turbidity for the five scenarios simulated using QUAL II.

Conclusions from QUAL II scenarios

23. Part IX presents the conclusions from the simulations for water temperature, suspended sediments, and turbidity for the five scenarios simulated using QUAL II.

PART II: MODELING APPROACH FOR CE-THERM-R1

24. As part of the water quality study, the Portland District requested the assistance of the Hydraulics Laboratory, WES, to model release water temperatures (based on the most recent target temperatures) and suspended sediments for the 10-year study period for each project. The predicted release parameters were used as headwater boundary conditions for the riverine modeling effort.

25. WESTEX, an in-house Hydraulics Laboratory model, was chosen as the one-dimensional reservoir model to simulate target release temperatures and suspended sediment concentrations for Lost Creek, Applegate, and Elk Creek projects. The WESTEX model was used to provide a technical approach consistent with previous model studies of temperature and turbidity at Lost Creek and Elk Creek Dams (USAED, Portland 1974, 1981). Because WESTEX has not been documented in detail, it has not received the recognition that other one-dimensional reservoir models have received. Therefore, to document the utility of the WESTEX model, CE-THERM-R1 was selected to make comparisons between results of release water temperatures and suspended sediments. The Hydraulics Laboratory and the Environmental Laboratory have addressed the comparison of WESTEX and CE-THERM-R1 in a separate report.*

Model Selection

26. CE-THERM-R1 is the thermal portion of CE-QUAL-R1 (a one-dimensional, numerical reservoir water quality model), which can be used independently of the full water quality model. It is a numerical model that describes the vertical distribution of thermal energy in a reservoir through time. CE-THERM-R1 simulates all the physical processes found in CE-QUAL-R1, including temperature, suspended sediments, and total dissolved solids as opposed to the 27 quality constituents simulated by CE-QUAL-R1. Assumptions made in CE-QUAL-R1 are also applicable to CE-THERM-R1.

27. Major reasons for selecting CE-THERM-R1 to model Lost Creek reservoir and compare with WESTEX are:

---

* Michael L. Schneider, Technical Report (in preparation), Hydraulics Laboratory, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

a. It is a well-known one-dimensional reservoir thermal model.

b. It is a generally accepted standard for modeling temperature in reservoirs and is widely used by Corps Districts, private national and international consulting firms, and universities.

c. It is well documented in Instruction Report E-82-1 (Environmental Laboratory 1982) and is supported by the WES.

d. It is relatively easy to use and economical.

Model Strengths and Limitations

28. CE-THERM-R1 has two major areas of application. First, it is used as a precursor to CE-QUAL-R1. Using CE-THERM-R1 can save time and money by reducing computer costs and data requirements when checking the water and heat budgets and calibrating physical parameters. It is important to correctly model temperature dynamics since so many water quality parameters in CE-QUAL-R1 are temperature dependent. The second application of CE-THERM-R1 is used in thermal studies of reservoirs and their tailwaters. By applying CE-THERM-R1, the user can study stratification cycles in reservoirs, determine location of selective withdrawal ports to meet downstream temperature objectives, and evaluate the effects of reservoir operational changes (i.e. change in minimum or maximum releases rates) on in-pool and downstream temperatures.

29. Limitations are placed on the use and interpretation of model results because of the assumptions made to simplify the real system. The major assumptions (Environmental Laboratory 1982) of CE-THERM-R1 are:

a. The model assumes a reservoir can be represented by a series of vertical well-mixed horizontal layers. The limitations imposed by this assumption are:

   (1) Longitudinal and lateral predictions of constituents cannot be made.

   (2) All inflow quantities and constituents are well mixed within the horizontal layers.

   (3) Model predictions are most representative near the dam or the deepest part of the reservoir.

b. CE-THERM-R1 is based on the principle of conservation of mass. The model considers mass added by inflows, mass removed by outflows, and diffusion of mass.

c. CE-THERM-R1 assumes that the density of water is a function of temperature and suspended and dissolved solids. The model uses density for vertical placement of inflows, computation of the outflow distribution, and vertical mixing processes.

Model Description

30. CE-THERM-R1 is a numerical one-dimensional temperature model that describes the vertical distribution of thermal energy in a reservoir through time. The reservoir is conceptualized as a vertical series of horizontal layers in which thermal energy and materials are mixed completely in each layer (Figure 2). The mathematical structure of the model is based on horizontal layers whose thicknesses vary depending on the balance of inflowing and outflowing waters. The use of variable layer size is an Eulerian-Lagrangian approach that removes vertical advection from the mass balance equation, thus eliminating advection-induced numerical diffusion from the solution.

31. The placement of inflowing waters among the horizontal layers is dependent on density differences; therefore, surface flows, interflows, and underflows can occur in the simulation. Outflows are also withdrawn from layers after consideration of layer densities, discharge rates, and outlet configuration.

32. Reservoir outflows may take place according to a specified schedule of port releases. Additionally, if a user wishes to meet a downstream temperature objective, specification of total flow release and desired release temperatures can be made (model selects port flow). Two modes of operation, normal and scheduled, can be simulated. Normal operation uses daily averaged port or weir outflows; scheduled operation is the specified peaking hydropower generation flows and durations that may occur within each day. Pumped-storage operations can also be modeled with this mode.

33. The heat budget includes components of short and long wave radiation, back radiation, reflected solar and atmospheric radiation, evaporative heat loss, conductive heat transfer, and gain or loss through inflow and outflow. Vertical transport of thermal energy and mass is achieved through entrainment and turbulent diffusion. Entrainment determines the depth of the upper mixed layer and the onset of stratification and is calculated from the turbulent kinetic energy influx generated by wind shear and convective mixing using an integral approach (Johnson and Ford 1981). Turbulent diffusion is a two-way transport process that incorporates a turbulent or eddy diffusion

coefficient that depends on wind speed, magnitude of inflows and outflows, and density stratification.

Assumptions Made in Modeling

34. The assumptions that were made to characterize the Lost Creek reservoir system were:

a. Lost Creek conditions near the dam, station 11, can be reasonably represented by a one-dimensional vertical model such as CE-THERM-R1.

b. All inflows are handled by specifying two tributaries, upper Rogue River and South Fork Rogue River.

c. Meteorological data from Medford, OR, were assumed to apply at Lost Creek reservoir.

PART III: DATA REQUIREMENTS FOR CE-THERM-R1

Observed Data

35. Four types of data are required for the simulation of CE-THERM-R1: initial conditions, boundary conditions, model coefficients, and calibration/verification data. Initial conditions represent the state of the water quality constituents at the start of the simulation. Boundary conditions represent the driving variables, such as meteorological data, inflows to reservoir, and controlled outflow releases. Model coefficients are constants used in algorithms that comprise CE-THERM-R1, and calibration/verification data refer to observed field data which are compared to model predictions.

36. The Portland District provided all of the observed data except model coefficients for the years modeled (1981, 1984, and 1986). Much of the data required by CE-THERM-R1 were also required by QUAL II. For instance, flows at the upper Rogue River "below Prospect" gaging station and flows at the South Fork Rogue River "south of Prospect" gaging station (Table 1) were used as inflows to Lost Creek reservoir for the CE-THERM-R1 application. For the QUAL II application, flows at these two gaging stations were simulated as a headwater boundary condition and tributary inflow (respectively) for predam conditions.Also, controlled outflow releases served as a boundary condition for both CE-THERM-R1 and QUAL II applications. Additionally, meteorological data used in the CE-THERM-R1 application were required by QUAL II with the exception of dew point temperature. QUAL II requires wet bulb temperature instead of dew point temperature.

37. Meteorological data required by CE-THERM-R1 (cloud cover, dry bulb and dew point temperature, air pressure, and wind speed) were obtained from weather data tapes for the weather station at Medford, OR, a first-order meteorological station. Two first-order weather stations were located in or near the study area: Medford and Sexton Summit, OR. The Medford station was chosen to represent weather conditions for the portion of the Rogue River being modeled since it was located approximately 30 miles southwest of Elk Creek Dam and was most representative of conditions in the river valley. The US Air Force Environmental Technical Applications Center in Asheville, NC, provided hourly data up to December 1985, which were reduced to daily values

Table 1

Observed Data Used for Elk Creek Study

Data Type	Source	Gaged Station Name	Station Number	Location	Extent*	Comment
Stage/discharge	USGS Portland	below Prospect	14330000	RM 169	1978-1987	Rogue River
		at McLeod	14335075	RM 156		
		near McLeod	14337600	RM 154		
		at Dodge Bridge	14339000	RM 138		
		at Raygold	14359000	RM 125		
		at Grants Pass	14361500	RM 102		
		near Agness	14372300	RM 30		
Tributary stage/ discharge	USGS Portland	S. Fork s. of Prospect	14334700	RM 2.4		South Fork Rogue
		Big Butte near McLeod	14337500	RM 0.60		Big Butte Creek
		near Trail	14338000	RM 0.40		Elk Creek
		Bear Creek at Medford	14357500	RM 10		Bear Creek
		near Copper	14362000	RM 46		Applegate River
		near Applegate	14366000	RM 27		Applegate River
		near Wilderville	14369850	RM 6		Applegate River
Temperature	USGS Portland	below Prospect	14335075	RM 169		Rogue River
		at McLeod	14335075	RM 156		
		near McLeod	14337600	RM 154		
		at Dodge Bridge	14339000	RM 138		
		at Raygold	14359000	RM 125		
		at Grants Pass	14361500	RM 102		
		near Merlin	14370400	RM 86		
		near Marial	14372250	RM 49		
Tributary temperature	USGS Portland	S. Fork s. of Prospect	14334700	RM 2.4		South Fork Rogue
		Big Butte near McLeod	14337500	RM 0.6		Big Butte Creek
		near Trail	14338000	RM 0.4		Elk Creek
		near Copper	14362000	RM 46		Applegate River
		near Applegate	14366000	RM 27		Applegate River
		near Wilderville	14369500	RM 6		Applegate River

(Continued)

* Mor· data were available but were not used for this application.

Table 1 (Concluded)

Data Type	Source	Gaged Station Name	Station Number	Location	Extent	Comment
Suspended sediments	USGS Portland	below Prospect	14335075	RM 169	1978-1981	Rogue River
		at McLeod	14335075	RM 156	1978-1981	
	DEQ*	at Dodge Bridge		RM 138	1978-1987	
	DEQ	at Gold Hill		RM 119	1978-1987	
	DEQ	at Grants Pass		RM 102	1978-1987	
	DEQ	at Robertson Bridge		RM 87	1978-1987	
Tributary suspended sediments	USGS Portland	S. Fork s. of Prospect	14334700	RM 2.4	1978-1987	South Fork Rogue
Turbidity	USGS Portland	below Prospect	14335075	RM 169	1978-1987	Rogue River
		at McLeod	14335075	RM 156	1978-1987	Rogue River
Tributary turbidity	USGS Portland	S. Fork s. of Prospect	14334700	RM 2.4	1978-1987	South Fork Rogue
		near Trail	14338000	RM 0.4	1978-1987	Elk Creek
		near Copper	14362000	RM 46	1978-1987	Applegate River
Cross sections	USGS Portland			RM 157-102		Rogue River
	USGS**			RM 102-76		Rogue River
	Field notes			RM 76-49		Rogue River
	USGS**			RM 16-0		Applegate River
	USGS†			RM 20-47		Applegate River
Rating curves	USAE Medford	near McLeod	14337600	RM 154	1978-1987	Rogue River
		Dodge Bridge	14339000	RM 138		Rogue River
		Raygold	14359000	RM 125		Rogue River
		Grants Pass	14361500	RM 102		Rogue River
		near Agness	14372300	RM 30		Rogue River
Tributary rating curves	USAE Medford	Big Butte near McLeod	14337500	RM 0.60		Big Butte Creek
		near Trail	14338000	RM 0.40		Elk Creek
		near Wilderville	14369500	RM 6		Applegate River
Meteorological	USAF††	Medford, Oregon				

* Oregon Department of Environmental Quality.
** Stepback Water Analysis.
† Open-File Report.
†† Environmental Technical Applications Center.

using a computer program called WEATHER (Hydrologic Engineering Center 1986). For 1986 and 1987, daily data for Medford were taken from monthly summaries of local climatological data published by the US Department of Commerce, National Climatic Data Center, Asheville, NC.

38. In-pool profile data taken in the reservoir at specified depth intervals were needed for calibration/verification of CE-THERM-R1. Temperature profile data were the only type of profile data available to calibrate and verify CE-THERM-R1. The temperature profiles taken at station 11 were chosen to represent conditions near the dam for calibration/verification of CE-THERM-R1 because of its proximity to Lost Creek Dam compared to the other monitored stations in the reservoir. Suspended sediment profiles were not available for calibration/verification purposes since they had not been measured for the years modeled.

Synthesized Data

39. Continuous records of flow, temperature, and suspended sediment data were required for daily updates during the CE-THERM-R1 simulations. Missing or unavailable flow and temperature data for the Rogue River "below Prospect" and South Fork Rogue River "south of Prospect" gaging stations were estimated using regression equations developed for the Rogue River system by Hamlin and Nestler (1987). Missing or unavailable suspended sediment data for both gaging stations were estimated using regression equations (Table 2) developed by the Portland District.

Data Manipulation

40. Seven percent of the area tributaries to Lost Creek Lake are unmonitored. Contributions from these areas were included in the total project inflow because of their importance in maintaining the water budget for the modeling effort. The total project inflow was calculated by adding the change in storage to the outflow from Lost Creek dam. Inclusion of the contribution of the ungaged tributaries to the gaged inflows to Lost Creek was calculated as follows:

Adjusted QPRO = QPRO/(QPRO + QSFK) * QINFLOW

Adjusted QSFK = QSFK/(QPRO + QSFK) * QINFLOW

where

QPRO = Rogue River below Prospect flow

QSFK = South Fork Rogue River flow

QINFLOW = calculated project inflow

Table 2

Suspended Sediment/Flow Relationships for Gaged and Ungaged Tributaries

Station	Status	Relationship	r^2	Prob > F
Below Prospect	Gaged	SS = -9.710 + 9.011EE-06*Q**2	0.74	0.0001
South Fork Rogue	Gaged	SS = 1.557 + 3.512EE-05*Q**2	0.78	0.0001
Big Butte Creek	Ungaged*	SS = 5.060 + 4.167EE-05*Q**2	0.998	0.0007
Trail Creek	Ungaged*	SS = 6.214 + 3.45EE-04*Q**2	0.9996	0.0001
Little Butte Creek	Ungaged*	SS = 7.66 + 5.66EE-05*Q**2	0.9995	0.0002
Bear Creek	Ungaged*	SS = 19.47 + 5.13EE-05*Q**2	0.993	0.0025
Evans Creek	Ungaged*	SS = 3.11 + 2.97EE-05*Q**22	0.9998	0.0001
Graves Creek	Ungaged*	SS = 0.796 + 8.56EE-05*Q**2	0.9998	0.0001
Little Applegate	Ungaged*	SS = 0.726 + 3.478EE-05*Q**2	0.9998	0.0001
Williams Creek	Ungaged*	SS = 1.219 + 4.582EE-05*Q**2	0.9997	0.0001

* Developed using four points from geographic information system.

PART IV: CE-THERM-R1 CALIBRATION/VERIFICATION

Temperature and Suspended Sediment Calibration

41. Temperature and suspended sediment calibration for Lost Creek reservoir was performed for water year 1986 (a normal water year). Calibration was performed by adjusting the coefficients that impact mixing in the reservoir (SHELCF, CDIFW, and CDIFF) until the predicted thermal profiles matched the observed. Explanation of each coefficient can be found in the User's Manual for CE-THERM-R1 (Environmental Laboratory 1982).

42. Calibration of CE-THERM-R1 was accomplished in several steps. First, the water budget of Lost Creek reservoir was checked. Volume discrepancies over the simulation period produced elevation differences well within 0.5 m (usually approximately 2 percent above the total volume of the reservoir).Second, coefficients affecting the heat budget were set to suggested values (in User's Manual); finally, adjustments to the mixing coefficients were made within the suggested range. Final values for the mixing coefficients (SHELCF, CDIFW, and CDIFF) were 1.0, 0.5×10^{-3}, and 0.5×10^{-3}, respectively.

43. The statistic used for comparison of predicted and observed (actual target water release temperature) profile data was the Reliability Index (RI) of Leggett and Williams (1981). This statistical comparison could be made only for temperature profiles since suspended sediment profiles were unavailable for all years modeled. The RI was calculated for temperature profiles on each sampling day for each observation depth. An average RI was calculated to give "goodness" of fit, and values could range from 1.0 (perfect fit) to infinity. The overall RI from the final calibration of Lost Creek Reservoir was 1.13. This was acceptable based on comparable RI values from other Corps studies, which have been 1.08 for DeGray Lake, 1.09 for Eau Galle Lake, and 1.14 for Table Rock Lake. Figure 3 shows predicted (solid line) versus observed (dots) temperature profiles for the final calibration.

44. Comparisons of predicted and observed release water temperature for 1986 were made using the absolute mean error (AME) and root mean square error (RMSE). The absolute mean error was calculated as

$$AME = \Sigma(\text{PREDICTED} - \text{OBSERVED})/\text{NUMBER OF OBSERVATIONS} \qquad (1)$$

and the root mean square error was calculated as

$$\text{RMSE} = [\Sigma(\text{PREDICTED} - \text{OBSERVED})^2/\text{NUMBER OF OBSERVATIONS}]^{0.5} \quad (2)$$

45. The RMSE is a measure of variability between predicted and observed values. For instance, an RMSE value of 0.50 means that the predicted data are within ±0.50 of the observed value 67 percent of the time. The sign of the AME indicates whether the predicted results average higher (+) or lower (-) than the observed data.

46. The monthly AME values for 1986 (Table 3) indicated that during fall and winter months, CE-THERM-R1 release temperature predictions were too cool, and during the spring and summer months, predictions were too warm. In general, the yearly AME value indicated that CE-THERM-R1 was predicting too cool (-0.30° C) for the whole year. The monthly RMSE values (Table 3) for most of the year were well within 1° C. However, late summer and fall RMSE values ranged from 1.19° to 1.49° C (Table 3). These higher RMSE values were probably due to CE-THERM-R1 consistently underpredicting water temperatures in

Table 3

AME and RMSE Values Calculated for Release Temperature (°C) from CE-THERM-R1 Simulations for Each Month and Entire Year for All Years Modeled

	1981		1984		1986	
Month	AME	RMSE	AME	RMSE	AME	RMSE
Jan	0.12	0.36	-0.29	0.30	0.00	0.00
Feb	-0.08	0.25	-0.29	0.30	-0.38	0.44
Mar	-0.49	0.52	-0.52	0.54	-0.29	0.31
Apr	-0.54	0.62	-0.58	0.62	-0.25	0.48
May	0.15	0.56	-0.40	0.57	0.42	0.55
Jun	0.38	0.61	-0.33	0.65	0.73	0.81
Jul	0.49	1.16	0.56	1.25	-0.72	0.74
Aug	0.66	0.86	0.44	1.15	0.75	1.36
Sep	-0.13	0.49	-0.38	1.10	0.19	1.49
Oct	-0.80	0.82	-1.38	1.42	-1.44	1.45
Nov	-0.86	0.88	-0.60	0.83	-1.18	1.19
Dec	-0.51	0.60	-0.41	0.55	-0.93	0.94
Year	-0.13	0.70	-0.34	0.88	-0.30	1.03

the region of the withdrawal zone for this time of year. The yearly RMSE value was 1.03° C.

Temperature and Suspended Sediment Verification

47. Temperature verification was performed on water years 1981 (a dry year) and 1984 (a wet year) for in-lake profiles. Results for RI were 1.14 and 1.09, respectively, values that were comparable to the RI for calibration. Temperature profiles for these years are illustrated in Figures 4 and 5. Suspended sediment profiles for these years were not available to verify suspended sediment concentrations in-lake.

48. Predicted release water temperatures for 1981 and 1984 were again compared to observed values (actual target water release temperatures) using the AME and RMSE. For both years, monthly AME and RMSE for all months were similar to values for 1986 (Table 3). During the fall of both years, CE-THERM-R1 did not underpredict release temperatures as much as in 1986. In general, the yearly AME values indicated that CE-THERM-R1 was predicting too cool (-0.13° C in 1981 and -0.34° C in 1984) for both years. The monthly RMSE values (Table 3) for most of both years were well within 1° C. The yearly RMSE for the both years was 0.70 and 0.88, respectively.

49. Comparisons between predicted and observed release suspended sediment values were made for 1981 since observed data were available for this year. The mean predicted suspended sediment concentration of the releases was 1.18 mg/ℓ compared with an observed mean of 1.6 mg/ℓ, an underprediction of 0.42 mg/ℓ. The calculated observed mean release value was greatly influenced by the dominance of low-flow/low-discharge observations. The values available during normal to low flows were usually less than 3 mg/ℓ. Mean RMSE values for CE-THERM-R1 indicated that the model would predict within (±) 2.12 mg/ℓ 67 percent of the time (see tabulation that follows).

Month	AME	RMSE
Jan	0.13	1.34
Feb	1.31	1.36
Mar	-0.72	4.45
Apr	0.97	1.21
May	-0.49	1.56
Jun	0.02	0.19
Jul	--*	--
Aug	--	--
Sep	--	--
Oct	0.52	0.96
Nov	0.43	0.62
Dec	1.94	2.13
Year	0.42	2.12

* Missing value.

50. Even though the yearly RMSE was greater than the mean suspended sediment release value, CE-THERM-R1 was able to predict general trends in suspended sediment releases for flow events occurring during the year. This was considered acceptable.

PART V: MODELING APPROACH FOR QUAL II

51. The remainder of this report discusses the riverine modeling effort using the modified version of the USEPA one-dimensional riverine model QUAL II. Topics to be discussed include model selection, QUAL II strengths and limitations, model description, model modifications, assumptions, data requirements, calibration/verification, scenario results, and conclusions.

Model Selection

52. Selection of a numerical model to represent a system is based on issues to be addressed, characteristics of the system, and model availability.

53. Although several riverine water quality codes were available that can predict flow, temperature, and suspended sediments, QUAL II was selected for the Elk Creek study for the following reasons:

- a. It can simulate water quality conditions (in this case, flow, temperature, and suspended sediments) in a stream network.
- b. It can be applied under varying (at 3-hr intervals) meteorological conditions.
- c. It is relatively easy to use.
- d. It is well documented and supported by the USEPA.
- e. It is widely used and a generally accepted standard for use in water quality under one-dimensional (longitudinal), steady-flow conditions.
- f. It is economical to use, thus allowing long-term simulations on Corps minicomputers and microcomputers.
- g. It has the capability to model other water quality constituents that could be used in the future if required.
- h. It has already been applied to the Rogue River system in a previous study (Hamlin and Nestler 1987) to predict longitudinal water temperatures from Lost Creek Dam to Marial; with time a critical factor of the study, using the partially completed stream network proved to be expedient.

QUAL II Strengths and Limitations

54. QUAL II is an extremely useful water quality management tool that has been instrumental in evaluating the impact (i.e., magnitude, quality, and location) of changes in loadings on in-stream water quality (National Council

of the Paper Industry for Air and Stream Improvement, Inc. (NCASI) 1982). It can also be used in conjunction with stream water quality monitoring to identify magnitudes and quality characteristics of nonpoint source waste loads. If the user is interested in the effects caused by algae growth and respiration on dissolved oxygen concentrations, QUAL II can be used in the dynamic mode to model diurnal effects on dissolved oxygen. Also in the dynamic mode, the user can study the impact on water quality caused by a slug loading (such as a spill).

55. QUAL II's major limitations are its steady flow assumption and its constant inflow boundary concentrations. QUAL II is hydraulically limited to time periods of essentially constant flows in the stream network. Long simulations (i.e., entire year or a season) could not be modeled with any accuracy because of the normal variations in flow. Modifications to QUAL II were required to allow for time-varying flows and boundary conditions. These modifications will be discussed in a later section.

Model Description

56. QUAL II is a one-dimensional riverine water quality model with the capability of simulating up to 13 water quality constituents of any branched stream. Constituents that can be modeled in any combination by the user are listed below (NCASI 1982).

a. Dissolved oxygen.
b. Biochemical oxygen demand.
c. Temperature.
d. Algae as chlorophyll a.
e. Ammonia as N.
f. Nitrite as N.
g. Nitrate as N.
h. Dissolved orthophosphate as P.
i. Coliforms.
j. Arbitrary nonconservative constituent.
k. Three conservative constituents.

57. These constituents can be simulated in a steady-state mode (the time derivative of concentration is omitted from the mass balance equation, and the solution is computed in a single iteration) or dynamic mode

(concentrations can change with time). It solves the time-dependent water quality constituent transport equation, allowing for description of advection, dispersion, and sources/sinks. This equation is referred to as the energy equation for temperature or the differential mass balance equation for other constituents.

58. Hydraulic conditions (flow rate and depth) used within the energy and mass balance equations are determined from steady, nonuniform flow conditions by satisfying continuity and using stage-discharge relationships or solving Manning's equation with channel geometry information. Steady flow implies that the flow, velocity, width, and depth at a given point in the stream network are constant with time. Nonuniform flow allows velocity, flow, width, and depth to change in the longitudinal direction from reach to reach.

59. QUAL II approximates the river system by subdividing the stream system into reaches (the basic division of the model). Reaches represent portions of the river having similar channel geometry, hydraulic characteristics, and chemical/biological coefficients. Reaches are further divided into equally spaced units called computational elements. Figure 6 shows how QUAL II conceptualizes a river basin (NCASI 1982). Each computational element has inputs, outputs, and reaction terms. The energy and differential mass balance equations are solved simultaneously (implicitly) for each computational element.

60. Computational elements are connected in the direction of flow to form reaches; thus, the output from one element becomes the input to the next element downstream. QUAL II recognizes seven element types depending on the type of input and/or output and the location in the stream network. The following tabulation identifies the flags (identifiers) for each computational element (NCASI 1982).

Identifying Number	Type of Element
1	Headwater element
2	Ordinary element
3	Element upstream of junction on the main stem of river
4	Junction element
5	Last element in system
6	Element with a point source
7	Element with a withdrawal

61. A type 1 element represents a headwater element of a tributary as well as the main stem of the river system, and as such must always be the

first element in a reach. An ordinary or standard element (2) is one that cannot be classified as any of the other types of elements; the only input permitted in a standard element is incremental inflow. The type 3 element is used to designate an element on the main stem of the river just before a junction element (type 4) which has the simulated tributary entering it. Element type 5 represents the last element in the system, and there should be only one of this type. The remaining two types of elements (6 and 7) are those that have inputs (waste loads, returns, and unsimulated tributaries) and water withdrawals, respectively.

62. Longitudinal changes in water quality constituents are obtained by solving the differential mass and/or energy balance equation at the beginning of one of the headwater reaches and continuing downstream until a junction is encountered. Once a junction is encountered, the mass balance equations are solved for all the computational elements in the other reaches entering the junction before continuing beyond the junction. The result is a set of partial differential equations equal to the number of computational elements in the system. These partial differential equations are linked through the inputs and outputs of each element and are solved using an implicit finite difference procedure employing the Thomas algorithm (NCASI 1982).

63. The stream network (Figure 1) for scenarios 2 through 5 included 108 miles of the Rogue River extending below Lost Creek Dam to Marial (same as the previous study on the Rogue River) (Hamlin and Nestler 1987). Also included were approximately 47 miles on the Applegate River extending from Applegate Dam to the confluence of the Rogue and Applegate Rivers. Simulation of scenarios 4 and 5 included 1.8 miles on Elk Creek and extended from the proposed damsite to the confluence of the Rogue River and Elk Creek. Simulation of predam conditions (scenario 1) required additional modeling upstream of Lost Creek Dam for a total 121 miles simulated on the main stem of the Rogue River.

64. The system was then divided into reaches and further divided into elements. A total of 93 reaches for scenario 1 were subdivided into a total of 588 elements. For scenarios 2 through 5, a total of 90 reaches were subdivided into a total of 551 elements. Elements were equally spaced 1,500 ft apart for all simulations. A total of three headwaters (Lost Creek Dam or Prospect gaging station, Applegate Dam or Copper gaging station, and Elk Creek Dam or Elk Creek "near Trail" gaging station) and 11 point sources

representing tributaries (12 for scenario 1) comprised the Rogue River system. Of all the tributaries included in the study, Elk Creek and Applegate River were the only ones treated as branched reaches since cross-section data were available. The rest were treated as point sources. In addition, irrigation withdrawals and returns were not considered in the system because of limited information; additionally, sensitivity analysis from the previous study (Hamlin and Nestler 1987) showed no significant influence of these flows on water temperature in the Rogue River during summer flow periods.

Model Modifications

65. Modifications to the code of QUAL II were necessary to accommodate the study needs. These study needs were: (a) allowing time-varying (daily) updates, (b) allowing a daily time step, and (c) calculation and output of water surface and bottom elevations. Modifying QUAL II for time-varying (daily updates) discharge and quality (i.e., temperature and suspended sediments) at inflow boundaries was necessary to provide a more realistic simulation of the Rogue River. Updating the inflow rate results in changing the flow instantaneously throughout the reach because QUAL II is based on the steady flow assumption and does not provide for an unsteady flow routing. Use of the flow update feature provided acceptable results as long as discharge update intervals were large with respect to the travel time of the system and the percent change in flow was small.

66. As an example, suppose the travel time through the system was approximately 3 days and the discharge was updated from 1,000 cfs on Julian day 100 to 1,500 cfs on Julian day 101. For this case, a phase error would occur at the most downstream stations because the 1,500-cfs flow would instantaneously replace the 1,000-cfs flow throughout the downstream reaches. In fact, the water quality associated with this higher flow would not reach these stations until after the 1,000 cfs flow cleared the system. Therefore, every time there is a flow update, some error is introduced for a period (equivalent to the reach travel time). However, for this application the phase error is kept small because the flow update intervals are much larger than the travel time and the amount of flow change is relatively small.

67. Water quality constituents in QUAL II can be computed in either a steady-state mode or dynamic mode. In the dynamic mode, QUAL II uses a time

step that is as short as 1 hr. The second modification to the code was to allow a time step as large as 24 hr and to provide daily average values for the output. The 24-hr time step decreased the run time for a simulation of QUAL II, allowing efficient yearly simulations.

68. Finally, QUAL II was modified to calculate the values for water surface elevation and bottom elevation for each element in the system. These variables were used to aid the hydraulic calibration efforts.

Assumptions Made in QUAL II Modeling

69. Models are a simplified representation of a complex system that can be used for less cost and within a shorter period of time than required for experimentation on the real system. Consequently, simplifying assumptions have to be made for the system. For the Elk Creek study, the major simplifying assumptions were:

- a. Meteorological data from Medford, OR, were applicable over the entire study reach.
- b. Temperature and suspended sediments were transported in the longitudinal direction (direction of flow), and each element was completely mixed laterally and vertically.
- c. The type of suspended sediment responsible for most of the turbidity was assumed to be smectite clay and, as in the case of the Willamette Basin, is usually suspended over the entire length of the stream and settles only in tranquil waters or the ocean (USAED, Portland 1974).
- d. Suspended sediments were assumed to behave as a conservative constituent, which neither decays nor interacts with other constituents (i.e., no loss due to settling and no resuspension from bed).
- e. Ungaged tributaries were assumed to be point sources and were completely mixed at junction nodes.
- f. Ground-water recharge on the Applegate River was assumed to be lateral inflows that had a constant temperature value the same as average annual air temperature (for the 10-year study period).
- g. Tributary flows for Little Applegate and Williams Creek were assumed to be equal to differences between the "at Copper" and the "at Applegate" gaging stations and the "at Applegate" and the "near Wilderville" gaging stations, respectively (Figure 1).

PART VI: DATA REQUIREMENTS FOR QUAL II

Observed Data

70. Numerical models require observed data for calibration and verification purposes. The Portland District provided all of the observed data for this study. The sources and types of observed data are listed in Table 1.

71. Cross-section data used from the previous study (Hamlin and Nestler 1987) were obtained from the USGS for RM 76.5 to RM 157.4 on the Rogue River. In addition, channel geometry data were obtained from the Portland District for RM 157.4 to 169.4 on the upper Rogue River for simulating predam conditions. Cross-section data obtained by WES in conjunction with the Portland District during a site inspection field trip of July 1985 were used for RM 76 to RM 49. However, in comparison to the cross-section data obtained from the USGS, the cross-section data used from the field trip were not measured as frequently or with the accuracy of the data obtained from the USGS. Cross-section data on the Applegate River and Elk Creek were also obtained from the USGS. Cross-section data for RM 16 through RM 20 on the Applegate River were not available; thus, channel geometry was assumed to be the same as what occurred at RM 16. Quad maps were examined to ensure that major changes in slope or relief were not occurring in this section of the Applegate River.

72. Meteorological data required by QUAL II (cloud cover, dry bulb and wet bulb temperature, air pressure, and wind speed) were obtained from weather data tapes for the weather station at Medford, OR, a first-order meteorological station. As discussed in Part III, the Portland District obtained tapes containing hourly meteorological data up to December 1985 from the US Air Force Environmental Technical Applications Center in Asheville, NC. The hourly values were reduced to daily values using a computer program called WEATHER (Hydrologic Engineering Center 1986). For 1986 and 1987, daily data for Medford were taken from monthly summaries of local climatological data published by the US Department of Commerce, National Climatic Data Center, Asheville, NC.

73. Daily precipitation data were used in the suspended sediment regression analyses performed for the Rogue River "below Prospect" gaging station and the South Fork Rogue River "south of Prospect" gaging station. Precipitation data for these stations were obtained from 1978-1987

climatological publications of the National Oceanic and Atmospheric Administration.

Synthesized Data

74. Continuous records of flow, temperature, and suspended sediment data were required for daily updates during the QUAL II simulations. Missing or unavailable flow and temperature data for the gaged and ungaged tributaries were estimated using regression equations developed for the Rogue River system (Hamlin and Nestler 1987). Missing or unavailable suspended sediment data for gaged and ungaged tributaries were estimated using regression equations (Table 2) developed by the Portland District.

75. The daily equilibrium temperatures and coefficients of surface heat exchange required by the temperature regression equations were calculated using the Heat Exchange Program called HEATX (Eiker 1977). In addition to meteorological data, HEATX requires project information such as latitude, longitude, elevation, and reflectivity of the ground surrounding the body of water. Changing the latitude, longitude, and elevation from those at Medford to those at each project changed the calculated values of equilibrium temperature by less than 2 percent. Because of the small difference in values, it was decided not to adjust the data for difference in location. A surface reflectivity coefficient of 0.20 was used, which corresponds to early summer vegetation and leaves with a high water content.

PART VII: QUAL II CALIBRATION/VERIFICATION

Background

76. Model calibration requires iterative comparisons of model output to historical data for refining and adjusting model parameters until optimal model predictions are obtained. Water quality model calibration can be broken into two phases. First, calibration of model hydraulics is performed until predicted behavior of the stream hydraulics is in agreement with observed hydraulic behavior. After the completion of hydraulic calibration, water quality calibration is performed until water quality predictions are in agreement with observed water quality values. A second data set is used after the completion of calibration to verify that the model produces acceptable predictions. A calibrated and verified model can then be used to simulate the behavior of the prototype under a variety of operational and meteorological conditions.

Hydraulic Calibration

77. Hydraulic calibration of QUAL II for the Rogue River system had been partially completed from Lost Creek Dam to Marial in a previous study (Hamlin and Nestler 1987) by comparing predicted water surface elevations and depths with observed values. For the Elk Creek study, hydraulic calibration was completed by adding two new sections to the original stream network. Each new section was calibrated separately, then added to the existing calibrated stream network. Calibration of these new sections was accomplished by adjusting Manning's n values until predicted water depths were in agreement with values from the USGS rating curves for observed flows at gaging stations located within these sections.

78. The two new sections were (a) approximately 47 miles on the Applegate River extending from Applegate Dam to the confluence of the Rogue and Applegate Rivers and (b) approximately 15 miles of the upper Rogue River extending from the Rogue River "near McLeod" gaging station upstream to the Rogue River "below Prospect" gaging station. The upper Rogue River reach was modeled only for scenario 1, predam conditions. The model was not calibrated

for conveyance times since travel time data were unavailable for the Rogue or Applegate Rivers or Elk Creek.

79. Hydraulic calibration of the Applegate River section was accomplished using depth (from USGS rating curves) and observed flow data for water year 1985 (a normal water year). These data were available at the "near Wilderville" gaging station (Figure 1) on the Applegate River. Hydraulic calibration of the upper Rogue reach was accomplished using depth and observed flow data for water year 1976 (predam conditions). These data were available at the "Rogue near McLeod" gaging station for this section.

80. Depth and flow for the Applegate River reach were compared at two constant discharge rates (a high and low flow rate) from the dam. A high discharge of 575 cfs that occurred 1 week in May 1985 was used for the high flow rate, and a low discharge rate of 100 cfs that occurred 1 week in February was used for the low flow rate. An AME (Equation 1) was calculated and used to evaluate calibration results.

81. On the Applegate River, predicted depths and flows from calibration runs were compared to observed flows and depths (from USGS rating curves) for the "near Wilderville" station using Equation 1. Hydraulic calibration was performed until predicted depths and flow were in agreement with observed values. Final calibration under low-flow conditions on the Applegate River produced an AME for depth of 0.28 ft at a mean depth of 2.91 ft and an AME for flow of 3.7 percent above observed flows. Final calibration under high-flow conditions produced an AME for depth of -0.32 ft at a mean depth of 3.21 ft and an AME for flow of 5.4 percent above observed flows.

82. Depth and flow for the upper Rogue River reach were also compared at two constant discharge rates. A high discharge of 2,900 cfs that occurred 1 week in May 1976 was chosen for the high flow rate, and a low discharge rate of 1,000 cfs that occurred 1 week in September was chosen for the low flow rate.

83. On the upper Rogue River, predicted depths and flows from calibration runs were compared to observed flows and depths (from USGS rating curves) for the "near McLeod" station using Equation 1. Again, hydraulic calibration was performed until predicted depths and flow were in agreement with observed values. Final calibration under low-flow conditions produced an AME for depth of -0.45 ft at a mean depth of 1.4 ft and an AME for flow of a 0.58 percent above observed flows. Final calibration under high-flow conditions produced

an AME for depth of 0.34 ft at a mean depth of 3.9 ft and an AME for flow of 0.58 percent above observed flows.

Temperature and Suspended Sediment Calibration/Verification

Background

84. Temperature calibration was performed separately on the two new sections which were added to the original stream network system (identified in the previous section). During temperature calibration, Manning's n values were adjusted to obtain optimal water temperature predictions. Even though Manning's n is a hydraulic calibration coefficient, it was adjusted in temperature calibration because it could increase or decrease both the travel time of water and the surface-to-volume ratio, thus allowing the cooling or warming of water within a reach. Minor adjustments of Manning's n values, not exceeding 0.010, were tested. If adjustments to Manning's n values did not produce adequate results, bottom width and side slopes were adjusted only after careful reexamination of cross-section data indicated that values used for some reaches were initially incorrect and the new values for these reaches were more representative. If cross-section information was incorrect, depths for certain reaches could be overestimated or underestimated, causing temperature predictions to be off. At the conclusion of temperature calibration, the hydraulic calibration was rechecked to ensure that the model remained hydraulically calibrated.

85. Suspended sediments were not calibrated (adjustments to coefficients) because they were modeled as a conservative constituent not interacting with other constituents, and therefore not having any coefficients that required adjustments. Changes in concentrations of suspended sediments in the stream network were assumed due to loadings from gaged and ungaged tributaries.

Temperature calibration

86. Temperature calibration of the model was performed by comparing mean daily water temperature predictions at the elements corresponding to the locations of three gaging locations (two on the Applegate River and one on the upper Rogue River) to the observed mean daily water temperatures at the gages. The accuracy of mean daily water temperature predictions was evaluated using the AME (Equation 1) and the RMSE (Equation 2). The "near Copper" gaging

station (Figure 1) was excluded from the comparison because of its proximity to Applegate Dam. Plots of observed (dots) versus predicted (solid line) water temperatures and comparison statistics for the 1985 water year on the Applegate River and for the 1976 water year on the upper Rogue River are presented in Figures 7 and 8, respectively.

87. Satisfactory calibration of water temperatures on the Applegate River could not be achieved by adjustments to Manning's n, bottom widths, or side slopes. Temperatures were being predicted too warm at both the "at Applegate" and "near Wilderville" gaging stations (AME equaled +0.5 and +0.6, respectively). Flow records for these stations were examined during dry periods (i.e., periods of no rain for at least 2 weeks) to see if ground-water recharge might have helped lower the water temperatures. The records showed that, on the average, 30 cfs of ground-water recharge appeared to be added between these two gages. Ground water was added to the model as a lateral inflow with a constant temperature the same as the average annual ai temperature (Freeze and Cherry 1979). This addition to the Applegate section improved results.

88. Figures 7a and 7b show calibration results for the gaging stations "at Applegate" and "near Wilderville." These figures show that the RMSE increased as distance from the Applegate Dam increased. The error could be attributed to:

a. Use of synthesized water temperatures (discussed in a previous section) on the ungaged tributaries (Little Applegate River and Williams Creek) instead of actual values which were not available.

b. Overextension of the meteorological data from Medford, OR.

89. In spite of increased error at the "near Wilderville" station, model predictions for the 1985 water year were considered acceptable. The predictions for the 1985 calibration run were generally well within a RMSE of 1.0° C for the "at Applegate" gaging station, and the "near Wilderville" station had a RMSE of 1.08° C. The AME values for the two gaging stations indicated that the model was predicting approximately 0.3° C warmer at the "at Applegate" gaging station and 0.074° C cooler at the "near Wilderville" station. Predicted values at these stations are influenced by ungaged tributaries (Little Applegate and Williams Creek, respectively). Thus, the synthesized water temperatures on Williams Creek appear to be closer to actual temperatures that had occurred but had not been recorded.

90. Figure 8 shows the calibration results for the upper Rogue River at the "near McLeod" gaging station. Calibration for this section was achieved by making adjustments to Manning's n , bottom widths, and side slopes. Similar to the Applegate section, the RMSE increased as one moved downstream of the "below Prospect" gaging station. However, predictions at the "Rogue near McLeod" were within a RMSE of 1.0° C for the 1976 water year. The AME value indicated that the model was predicting approximately 0.08° C warmer than observed data. These errors are believed to be mainly due to overextension of meteorological data from Medford and not from phase errors or inaccurate flow estimates since the travel time through this section is thought to be less than a day and water temperatures were available for gaged tributaries.

Temperature verification

91. Model performance was verified against data from the 1981 and 1982 water years (Figures 9 and 10) on the Applegate River. The RMSE and AME values obtained for each station in the verification simulation were similar to the values for the 1985 calibration simulation. Water year 1981, however, had the highest RMSE, 1.28 at the "near Wilderville" station. This increased RMSE could have been caused by the synthesized tributary temperatures being underpredicted more for this year than the other years. Water year 1982 was a wet year and showed very similar results to the calibration year. In fact, at the "Applegate at Applegate" gaging station, results for RMSE as well as AME were slightly better than calibration results.

92. Verification for the upper Rogue River was attempted for the water year 1971 at the "near McLeod" gaging station (Figure 11). However, observed mean daily temperature data were not available as they were for 1976. Instead, maximum and minimum temperature values (USGS) were averaged to serve as observed mean daily temperature data. Errors were detected in the maximum and minimum temperature values around the middle of May, but could not be checked because the original data were not available. A temperature balance was performed on the data in question and showed that the observed data at the "near McLeod" gaging station could not be possible when using the "below Prospect" station (Figure 1) as boundary conditions with tributary inflows from South Fork Rogue and Big Butte. As a result, the upper Rogue River could be verified for only the first 4.5 months. The RMSE value during this time

period was 0.79, and the AME was -0.22 (Figure 11), indicating, in general, a slight underprediction (cooler water temperatures) for this time period.

Suspended sediment calibration

93. Suspended sediments required no calibration (adjustments to coefficients) since they were assumed to behave as a conservative constituent. This assumption was based on the fact that the suspended sediments causing turbidity in the Rogue River are mostly smectite clays (USAED, Portland 1974). As in the case on the Willamette River, these sediments are suspended over the entire length of the river and settle out only in tranquil waters or the Pacific Ocean. Therefore, changes in concentrations of suspended sediments throughout the stream system are a direct result of dilution or loadings from dams and gaged and ungaged tributaries.

94. Limited amounts of observed data were available for suspended sediment concentrations on the Rogue River. Water year 1979 was chosen to model suspended sediments, since calibration of water temperatures on the main stem of the Rogue River was also performed for water year 1979 (Hamlin and Nestler 1987) and observed data were available. Figure 12 shows the results of the suspended sediment simulation for stations "at Dodge Bridge," "at Gold Hill," "at Wilderville," and "at Merlin." All station locations are shown on Figure 1 except "at Gold Hill," which is at RM 138.0 (close to the "at Raygold" station). The AME values for the stations were -7.85, 13.88, 5.50, and 4.57, respectively. The RMSE values for the stations were 36.13, 42.86, 70.07, and 54.28, respectively.

95. In general, suspended sediment predictions were close to observed values (Figures 12a-d) except during periods of high flow events (usually occurring during the wet seasons). Suspended sediment concentrations were usually underpredicted during these events. Several reasons can be given for this. First, underpredictions could be caused by inaccurate estimates of loadings from tributaries during the wet season. Depending upon the time of year, the amount of loadings can vary, even with the same flows coming from the same tributaries. For instance, during the winter season when ground cover is reduced, more suspended sediments will enter the system than in the summer season when vegetation will help hold material in place. Time of year was considered when regression equations for suspended sediments of ungaged tributaries were initially being developed. However, regression results were best when all data were included in the analysis and not subdivided by season.

96. Second, the assumption of suspended sediments behaving as a conservative constituent may not be as applicable during high-flow events. Resuspension of sediments may be occurring in turbulent flows causing an increase in suspended sediments, and material other than smectite clays may be transported. However, data are not available to test the resuspension theory. Lastly, observed data used in comparisons to predicted data were grab samples whereas predicted values of suspended sediments were mean daily averages. Since sampling times of the grab samples were not known, it could not be determined where on the flow hydrograph sampling took place. These problems make it difficult to derive conclusions from the suspended sediments simulation.

Suspended sediment verification

97. Water year 1978 was used in verifying suspended sediments. Results from this simulation are presented for stations "at Dodge Bridge," "at Gold Hill," "at Wilderville," and "at Merlin" (Figure 13a-d). The AME values for each station were -8.30, -5.20, 3.71, and -0.71, respectively. The RMSE values for each station were 35.68, 16.45, 9.20, and 4.34, respectively. Generally, the results were better than the results for water year 1979, probably due to better estimates of suspended sediments coming from ungaged tributaries.

PART VIII: QUAL II SCENARIO RESULTS

98. Each scenario (listed below) was simulated for the 10-year study period (1978 through 1987) to evaluate project impacts on the Rogue River once calibration/verification of the new reaches had been completed:

a. Predam conditions (scenario 1).

b. Lost Creek Dam operating only (scenario 2).

c. Lost Creek and Applegate Dams operating (scenario 3).

d. Lost Creek, Applegate, and Elk Creek (full pool) operating (scenario 4).

e. Lost Creek, Applegate, and Elk Creek (minimum pool) operating (scenario 5).

Reaches were added or deleted to the original stream network (Hamlin and Nestler 1987) depending on which scenario was being simulated. For example, the upper reach of the Rogue River was added only during predam simulations, and the Applegate River reach was added for all scenarios.

99. For all scenarios, water temperature and suspended sediment were simulated using the riverine one-dimensional model QUAL II in the Rogue River system. Suspended sediment results (milligrams per liter) were then converted to equivalent turbidity values (Jackson Turbidity Units, JTU) using relationships (Table 4) at index stations developed by the Portland District. Analyses were performed to evaluate the cumulative impacts of project operations (Lost Creek, Applegate, and Elk Creek) on water temperature, suspended sediment, and turbidity in the Rogue River Basin at index stations.

100. Predictions of water temperature, suspended sediments, and turbidity on the Rogue River system are discussed in the following sections. Each discussion includes

a. Tables of mean monthly values by constituent for each scenario at index stations.

b. Detailed plots by constituent for select stations showing differing effects of a dry (1981), wet (1984), and normal water year (1986).

101. Changes in suspended sediment concentrations with distance from Lost Creek and Applegate Dams (Table 5) were also examined during high-flow months and dry season months on the Rogue and Applegate Rivers and are discussed at the end of the suspended sediment section.

Table 4

Turbidity-Suspended Sediment Relationships

Location	Status	Relationship	r^2	Number of Observations	Comments
Lost Creek	Regulated and unregulated	Turb = 1.205 + 0.227*SS	0.72	118	Based on LCO2† station above Lost Creek Lake
Elk Creek	Regulated and unregulated	LOG10(Turb) = 0.163 + 0.846*LOG10(SS)	0.84	278	Based on EK01†
Applegate	Unregulated	For SS < 45, LOG10 (Turb) = 0.4512 + 1.087*LOG10(SS)	0.71	129	Based on watershed data collected 1972-1974
		For SS ≥ 45, LOG10 (Turb) = 0.6273 + 0.5080*LOG10(SS)	0.95	20	
Applegate	Regulated	Turb = -1.086 + 1.002*SS	0.82	119	Based on USGS suspended sediment grab samples and nearest hourly turbidity value
All stations below projects	Regulated and unregulated	For SS < 15, Turb = 0.9906 + 0.7429*SS	0.29	472	Based on DEQ†† grab sample data since February 1977
		For SS ≥ 15, Turb = 7.384 + 0.4194*SS	0.80	36	

† Data collected by Portland District.
†† Data collected by Oregon Department of Environmental Quality.

Table 5

Distance of Gaging Stations on the Rogue and Applegate Rivers
Downstream of Lost Creek and Applegate Dams

Gaging Station	Below Lost Creek Dam, miles	Below Applegate Dam, miles
Rogue near McLeod	0.2	--
Rogue at Dodge Bridge	18.7	--
Rogue at Merlin	70.7	--
Applegate near Copper	--	0.2
Applegate at Applegate	--	19.2
Applegate near Wilderville	--	38.0

Temperature

102. The immediate impacts of Lost Creek Dam on water temperatures in the Rogue River are presented in Table 6 for the "at McLeod" gaging station (Figure 1). This station is 0.7 mile downstream of Lost Creek Dam releases and upstream of the Elk Creek and Applegate projects. Table 6 shows that operating Lost Creek Dam only (scenario 2) causes warmer water temperatures in the early winter and fall months and cooler water temperatures in the summer compared with predam conditions. Figures 14-16 show yearly temperature simulation results for predam (solid line) and postdam (dashed line) conditions at the "near McLeod" gaging station. Operation of Lost Creek dam reduces the variation in monthly minimum and maximum water temperatures released (Table 7). For example, during June 1981 (dry season month) for scenario 1, minimum and maximum values were 9.12 and 15.89, respectively. For scenario 2, minimum and maximum values were 8.33 and 9.97, respectively. This trend is also true for other years simulated.

103. The impacts of Elk Creek Dam on Elk Creek operating at minimum and full pool are presented in Table 8 for the "near Trail" gaging station. Operation of Elk Creek Dam at minimum or full pool has similar influence on water temperatures in Elk Creek as Lost Creek Dam had on water temperatures in the Rogue River. In general, water temperatures were warmer in November and December, and cooler in spring and summer months. Early January water temperatures, however, were cooler instead of warmer as compared to Lost Creek impacts on the Rogue River. Figures 17-19 present yearly temperature results for predam and postdam conditions on Elk Creek at the "near Trail" station.

Table 6

Ten-Year Average of Predicted Mean Monthly Temperature, "at McLeod" Gaging Station

Scenario	10-Year Average of Mean Monthly Temperature, °C											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	3.30	4.05	5.46	6.82	9.07	11.82	14.12	13.84	10.80	7.74	4.50	2.91
2	4.46	4.41	5.26	6.76	8.76	9.39	11.80	12.93	9.04	7.57	6.93	6.52
3	4.46	4.41	5.26	6.76	8.76	9.39	11.80	12.93	9.04	7.57	6.93	6.52
4	4.46	4.41	5.26	6.76	8.76	9.39	11.80	12.93	9.04	7.57	6.93	6.52
5	4.46	4.41	5.26	6.76	8.76	9.39	11.80	12.93	9.04	7.57	6.93	6.52

Table 7

Monthly Average, Maximum, and Minimum Temperature Values at the "at McLeod" Gaging Station on the Rogue River

Scenario	Year		Monthly Average, Maximum, Minimum Water Temperatures, °C											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1981	Ave	4.59	4.30	5.77	7.83	10.24	12.81	15.24	15.47	11.89	7.47	5.07	3.90
		Max	7.58	6.33	7.31	12.41	12.91	15.89	17.23	17.99	14.13	9.30	8.13	6.08
		Min	3.11	1.81	4.12	4.46	7.96	9.12	12.46	12.76	8.15	4.82	2.28	2.52
2	1981	Ave	5.19	4.56	5.27	6.87	8.86	9.07	11.46	12.97	8.87	7.85	7.57	6.23
		Max	5.46	4.72	5.63	8.21	9.68	9.97	14.27	13.62	12.69	8.37	8.68	7.20
		Min	4.78	4.38	4.76	5.91	8.37	8.33	8.61	12.11	6.48	7.12	6.05	5.09
1	1984	Ave	3.83	4.23	5.80	6.57	8.11	10.12	13.83	13.36	10.57	7.05	4.48	2.37
		Max	5.01	5.26	6.58	8.33	10.66	13.14	15.39	14.91	12.87	9.84	6.89	3.39
		Min	1.98	2.63	4.73	5.12	6.64	7.10	12.23	11.57	7.65	5.04	2.45	1.02
2	1984	Ave	4.75	4.34	5.24	6.86	8.75	9.18	10.97	12.99	9.01	8.47	7.29	5.16
		Max	5.25	4.70	5.83	8.13	9.34	9.41	13.58	13.60	12.05	8.96	8.97	5.68
1	1986	Ave	3.79	4.31	6.09	6.69	8.73	12.11	12.99	14.13	9.73	7.38	4.80	3.16
		Max	5.62	6.23	7.68	10.01	12.89	14.60	14.74	15.45	13.87	8.82	6.10	4.34
		Min	2.67	2.49	4.79	5.32	6.16	9.71	11.11	12.34	6.64	6.52	3.46	2.11
2	1986	Ave	4.47	4.67	5.32	6.91	8.78	9.13	11.62	12.93	8.49	7.44	7.25	5.57
		Max	4.87	5.77	5.78	7.94	9.33	9.97	13.99	14.21	12.31	8.04	8.08	6.15
		Min	4.35	4.32	4.70	5.85	8.36	8.46	8.58	11.87	6.24	6.67	6.27	5.34

Table 8

Ten-Year Average of Predicted Mean Monthly Temperature at the "Elk Creek near Trail" Gaging Station

Scenario	10-Year Average of Monthly Temperature, °C											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	4.32	5.44	7.36	9.72	13.81	18.06	21.69	21.67	16.88	11.77	6.44	4.03
2	4.32	5.44	7.36	9.72	13.81	18.06	21.69	21.67	16.88	11.77	6.44	4.03
3	4.32	5.44	7.36	9.72	13.81	18.06	21.69	21.67	16.88	11.77	6.44	4.03
4	5.01	5.26	6.15	7.97	9.96	11.33	10.87	12.67	9.43	7.32	7.27	6.35
5	4.43	4.91	5.90	7.37	9.84	12.04	15.02	15.46	11.44	9.00	7.31	5.90

The solid line represents scenario 1 (predam on Elk Creek), crosses represent scenario 4, and squares represent scenario 5. Predam water temperatures were warmer during the summer months for Elk Creek as compared to predam water temperatures at Lost Creek. This is probably due to Elk Creek being shallower, with less flow than the Rogue River; thus, Elk Creek water temperatures are warmer (Figures 17-19) than the main stem Rogue River temperatures. Operation of Elk Creek Dam reduced the variation in monthly minimum and maximum water temperatures released (Table 9) similar to results for Lost Creek operations. Elk Creek operations at full pool produced cooler temperatures during the summer and early fall months than operating at minimum pool.

104. The impact of operation of Elk Creek Dam on Rogue River water temperatures is best represented at the "at Dodge Bridge" (Figure 1) gaging station, which is downstream of the confluence of the Rogue River and Elk Creek. The 10-year average of mean monthly water temperatures at the "at Dodge Bridge" station for all scenarios is presented in Table 10. Addition of Elk Creek Dam operations (full or minimum pool) with Lost Creek Dam operating had minimal impact to water temperatures in the Rogue River for all months except September. During September, both operation scenarios for Elk Creek produced cooler water temperatures at the "at Dodge Bridge" station than scenario 2 (Lost Creek Dam operating only). Cooler water temperatures resulted at the "at Dodge Bridge" station because discharges during September (increased from predam conditions) were similar for both operation scenarios. Yearly temperature results for predam and postdam conditions at the "at Dodge Bridge" station for 1981, 1984, and 1986, respectively, are presented in Figures 20-22.

105. The impacts of operation of Applegate Dam on Applegate River water temperatures at the "near Copper" gaging station (Figure 1) are presented in Table 11. Operation of Applegate Dam had similar impact on water temperatures in Applegate River as Lost Creek Dam had on water temperatures in the Rogue River. In January, November, and December, water temperatures were warmer; the spring and summer water temperatures were cooler. Yearly temperature results for predam (solid line) and postdam (dotted line) conditions at the "near Copper" station for 1981, 1984, and 1986, respectively, are presented in Figures 23-25. Operation of Applegate Dam caused the variations in minimum and maximum water temperatures at the "near Copper" station, in general, to be reduced for the dry season months (Table 12). At the "near Wilderville"

Table 9

Monthly Average, Maximum, and Minimum Temperature Values at the "near Trail" Gaging Station on Elk Creek

			Monthly Average, Maximum, and Minimum Water Temperature, °C											
Scenario	Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1981	Ave	5.75	5.78	7.61	10.82	15.85	18.34	22.46	23.58	18.89	10.99	8.00	5.57
		Max	9.10	7.71	9.74	19.10	20.85	22.04	25.55	27.55	23.87	14.59	10.5	8.30
		Min	2.78	3.09	5.42	6.61	12.82	13.62	18.03	19.92	11.09	8.19	4.19	1.76
4	1981	Ave	5.06	5.33	6.22	8.31	9.75	10.36	10.50	13.29	10.07	6.86	7.59	7.31
		Max	6.68	6.54	7.02	10.54	11.07	12.28	12.34	16.57	13.37	7.41	8.59	7.76
		Min	4.51	4.72	5.28	6.42	8.61	8.97	9.00	11.75	6.63	6.52	6.99	6.46
5	1981	Ave	5.06	5.03	5.46	7.29	9.55	11.32	14.83	15.57	10.99	8.10	8.09	7.38
		Max	6.68	6.43	5.88	9.16	10.40	13.78	16.50	16.90	13.93	8.84	9.02	7.86
		Min	4.51	4.74	4.98	5.86	8.76	9.54	11.93	14.07	7.90	7.47	7.56	6.48
1	1984	Ave	4.52	5.35	8.17	10.25	12.41	15.41	22.77	22.49	17.65	10.84	6.90	4.20
		Max	6.70	6.61	10.99	15.17	17.54	22.49	25.59	25.34	21.68	15.87	8.55	6.11
		Min	1.32	3.91	6.11	6.33	7.52	9.62	20.35	19.15	12.74	6.68	4.96	1.75
4	1984	Ave	4.66	4.73	5.50	7.24	8.87	9.93	9.67	13.10	9.35	6.99	7.97	5.87
		Max	4.94	5.31	6.44	9.62	10.02	11.48	11.45	14.38	12.87	7.29	9.03	7.19
		Min	4.46	4.47	4.77	5.93	6.64	7.58	8.73	11.61	6.76	6.74	7.12	4.88
5	1984	Ave	4.66	4.73	5.59	7.14	8.96	9.95	14.56	15.43	11.91	8.91	8.46	5.89
		Max	4.94	5.04	6.63	8.38	10.05	11.40	16.78	16.44	15.36	10.09	9.82	7.24
		Min	4.46	4.44	4.93	5.90	7.82	9.16	11.41	14.32	9.21	8.39	7.31	4.88
1	1986	Ave	5.20	6.30	8.55	10.28	12.82	21.32	22.37	24.71	16.36	11.92	7.47	4.43
		Max	7.53	8.64	12.35	15.29	22.92	24.81	24.84	28.14	25.78	14.48	9.03	6.56
		Min	2.64	3.27	6.20	8.39	7.82	17.30	19.44	18.04	9.60	9.79	5.64	2.35
4	1986	Ave	5.27	5.74	6.86	8.26	10.88	12.37	13.79	10.61	9.02	8.60	8.05	7.29
		Max	5.66	6.82	8.13	11.16	13.72	13.31	16.17	13.25	13.21	9.27	8.35	7.84
		Min	4.89	4.77	5.83	6.62	9.19	10.79	11.41	8.66	6.78	7.48	7.79	6.59
5	1986	Ave	4.74	5.38	6.72	7.64	9.35	12.27	14.25	15.79	10.98	9.54	8.67	7.36
		Max	5.28	7.38	7.37	8.71	11.68	13.53	16.26	16.50	14.77	10.26	9.22	8.11
		Min	4.50	4.67	6.09	7.05	8.34	10.92	11.77	14.41	8.46	8.86	8.19	6.39

Table 10

Ten-Year Average of Predicted Mean Monthly Temperature at the "Rogue at Dodge Bridge" Gaging Station

Scenario	10-Year Average of Mean Monthly Temperature, °C											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	3.78	4.83	6.54	8.19	10.69	13.84	16.74	16.52	12.80	8.95	4.97	3.05
2	4.70	5.40	6.70	8.26	10.40	11.42	13.41	14.47	12.70	8.52	7.03	5.28
3	4.70	5.40	6.70	8.26	10.40	11.42	13.41	14.47	12.70	8.52	7.03	5.28
4	4.73	5.36	6.60	8.17	10.26	11.32	13.01	14.17	10.41	8.42	7.10	5.50
5	4.65	5.72	6.36	7.95	10.07	11.19	13.12	14.37	10.50	8.37	7.01	5.41

Table 11

Ten-Year Average of Predicted Mean Monthly Temperature at the "Applegate Near Copper" Gaging Station

Scenario	10-Year Average of Mean Monthly Temperature, °C											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	3.46	4.86	7.39	9.75	12.55	15.51	17.91	18.09	14.99	11.14	5.57	2.28
2	3.46	4.86	7.39	9.75	12.55	15.51	17.91	18.09	14.99	11.14	5.57	2.28
3	4.11	4.45	6.11	8.11	10.03	12.77	13.21	13.24	14.19	10.05	7.81	5.08
4	4.11	4.45	6.11	8.11	10.03	12.77	13.21	13.24	14.19	10.05	7.81	5.08
5	4.11	4.45	6.11	8.11	10.03	12.77	13.21	13.24	14.19	10.05	7.81	5.08

Table 12

Monthly Average, Maximum, and Minimum Temperature Values at the "near Copper" Gaging Station on the Applegate River

Scenario	Year		Monthly Average, Maximum, and Minimum Water Temperature, °C											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 or 2	1981	Ave	4.65	5.43	8.72	11.32	13.95	16.19	18.21	18.06	15.36	10.24	5.25	1.71
		Max	8.53	7.76	10.21	16.23	18.16	18.42	19.77	21.72	17.92	13.31	8.13	4.54
		Min	1.73	1.92	7.13	7.34	11.35	12.64	15.98	15.46	11.71	6.81	1.69	0.01
3	1981	Ave	4.84	4.82	6.28	8.14	10.44	13.07	13.14	13.21	13.74	10.25	8.20	6.18
		Max	5.44	5.29	6.72	9.45	11.80	13.28	13.42	13.83	15.21	11.28	9.95	6.56
		Min	4.27	4.37	5.72	6.79	9.20	12.91	12.97	12.85	8.44	8.96	5.67	5.68
1 or 2	1984	Ave	3.00	5.15	7.70	9.17	11.80	14.94	18.03	17.43	15.24	9.74	4.85	2.55
		Max	5.90	7.02	9.71	12.32	17.54	18.00	19.79	19.34	17.62	13.97	7.55	4.21
		Min	0.95	2.68	5.43	6.72	8.89	10.15	16.31	15.76	12.21	6.88	2.43	0.77
3	1984	Ave	4.19	3.94	5.66	8.00	9.45	12.60	13.14	13.15	14.24	9.49	6.99	4.25
		Max	4.86	4.19	7.07	9.03	11.28	13.24	13.37	13.47	15.51	14.13	7.83	5.33
		Min	3.67	3.70	4.22	6.89	7.99	11.43	12.97	12.89	13.00	6.61	5.49	3.52
1 or 2	1986	Ave	4.78	4.72	8.24	10.91	13.50	16.85	17.12	18.79	13.63	11.67	6.78	3.63
		Max	6.73	8.08	12.06	15.25	19.16	19.54	19.59	20.54	19.57	14.89	9.43	6.01
		Min	3.22	0.01	4.79	8.64	9.96	13.30	14.69	16.71	8.86	8.12	4.07	2.24
3	1986	Ave	4.40	5.15	6.41	8.01	10.49	13.14	13.14	13.17	13.86	9.86	8.34	5.47
		Max	5.08	6.08	6.77	9.14	12.30	13.63	13.45	13.26	15.12	12.43	8.95	6.65
		Min	4.00	4.68	5.88	6.84	9.13	13.02	13.00	13.02	11.00	8.34	6.87	4.60

gaging station on the Applegate River, differences in water temperatures become less between predam and postdam scenarios (Table 13) as compared to predam and postdam scenarios at the "near Copper" gaging station (Table 11). Two major tributaries (Little Applegate and Williams Creek) influence water temperatures between the gaging stations. The increased distance from Applegate Dam at the "near Wilderville" station allowed more time for water temperatures to reach equilibrium and decreased the influences of Applegate Dam on water temperature.

106. The impact of Applegate Dam on water temperatures in the Rogue River is best represented at the "at Merlin" gaging station because it is downstream of the confluence of the Rogue and Applegate Rivers. The 10-year average of mean monthly water temperature results at the "at Merlin" station for all scenarios is presented in Table 14. Operation of Applegate (scenario 3) as compared to scenario 2 had very little impact on the Rogue River temperatures for most of the year. Temperatures toward the end of the year increased slightly (Table 14). Figures 26-28 present yearly temperature results at the "at Merlin" station, illustrating the impacts of the Applegate project on the Rogue River.

Suspended Sediment

107. The impacts of operation of Lost Creek Dam on suspended sediment (SS) concentrations in the immediate tailwater of the Rogue River are presented in Table 15 at the "at McLeod" gaging station (Figure 1). In general, operation of Lost Creek Dam decreased suspended sediment concentration on the Rogue River at the "at McLeod" station (Table 15). Yearly suspended sediment results for predam (solid line) and postdam (dashed line) conditions at the "at McLeod" station for 1981, 1984, and 1986 are presented in Figures 29-31, respectively. Note that, in general, Lost Creek Dam decreased in suspended sediment concentrations.

108. The impacts of operation of Elk Creek Dam (at full and minimum pool) on suspended sediment concentrations in the immediate tailwater of Elk Creek are presented in Table 16 for the "near Trail" gaging station. Operation of Elk Creek Dam at full or minimum pool had similar impacts on suspended sediment concentrations in Elk Creek. Suspended sediment concentrations for both operation scenarios were increased from predam conditions for

Table 13

Ten-Year Average of Predicted Mean Monthly Temperature at the "Applegate at Wilderville" Gaging Station

Scenario	10-Year Average of Mean Monthly Temperature, °C											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	4.56	5.86	8.20	10.95	14.75	19.52	23.57	23.41	18.52	12.85	6.32	4.41
2	4.56	5.86	8.20	10.95	14.75	19.52	23.57	23.41	18.52	12.85	6.32	4.41
3	4.93	6.07	8.14	11.02	13.53	17.83	21.37	21.08	16.65	11.33	7.18	4.89
4	4.93	6.07	8.14	11.02	13.53	17.83	21.37	21.08	16.65	11.33	7.18	4.89
5	4.93	6.07	8.14	11.02	13.53	17.83	21.37	21.08	16.65	11.33	7.18	4.89

Table 14

Ten-Year Average of Predicted Mean Monthly Temperature at the "Rogue at Merlin" Gaging Station

Scenario	10-Year Average of Mean Monthly Temperature, °C											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	4.88	5.81	8.13	10.65	14.29	18.57	22.32	22.13	17.21	11.60	5.76	3.79
2	4.78	6.21	8.37	10.84	14.23	17.07	19.09	19.34	15.16	11.14	6.84	4.78
3	4.86	6.27	8.37	10.81	13.99	16.95	19.05	19.33	15.32	11.13	7.12	5.92
4	4.88	6.31	8.39	10.85	13.95	16.89	18.46	18.67	15.09	11.04	7.05	5.06
5	4.87	6.25	8.31	10.74	13.91	16.89	19.02	19.30	15.29	10.99	7.06	5.07

Table 15

Ten-Year Average of Predicted Mean Monthly Suspended Sediment Concentrations at the "at McLeod" Gaging Station

Scenario	10-Year Average of Monthly SS Concentrations, mg/ℓ											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	11.1	20.4	9.8	12.9	23.3	10.9	3.9	2.7	2.0	6.78	7.4	18.0
2	3.1	3.2	2.8	2.4	2.9	3.0	2.5	2.3	1.6	2.44	2.67	2.76
3	3.1	3.2	2.8	2.4	2.9	3.0	2.5	2.3	1.6	2.44	2.67	2.76
4	3.1	3.2	2.8	2.4	2.9	3.0	2.5	2.3	1.6	2.44	2.67	2.76
5	3.1	3.2	2.8	2.4	2.9	3.0	2.5	2.3	1.6	2.44	2.67	2.76

Table 16

Ten-Year Average of Predicted Mean Monthly Suspended Sediment Concentrations at the "Elk Creek Near Trail" Gaging Station

Scenario	10-Year Average of Mean Monthly SS Concentrations, mg/ℓ											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	10.7	15.5	7.9	5.1	1.9	0.7	0.8	0.5	0.8	7.67	8.11	12.22
2	10.7	15.5	7.9	5.1	1.9	0.7	0.8	0.5	0.8	7.67	8.11	12.22
3	10.7	15.5	7.9	5.1	1.9	0.7	0.8	0.5	0.8	7.67	8.11	12.22
4	9.2	10.0	10.5	9.5	8.3	7.6	7.6	6.9	7.0	6.80	9.11	9.33
5	9.9	10.6	10.5	9.6	8.3	7.8	7.3	7.0	8.0	9.56	10.78	8.78

most of the year (Table 16). Substantial differences in suspended sediment concentrations between operation scenarios occurred in September, October, and November when minimum pool operation produced greater suspended sediment concentrations.Yearly suspended sediment results for predam (solid line) and postdam conditions (crosses represent scenario 4, and squares represent scenario 5) at the "near Trail" station for 1981, 1984, and 1986 are presented in Figures 32-34, respectively. Note that Elk Creek Dam decreased suspended sediment concentrations during high-flow seasons for all years presented.

109. The impact of operation of Elk Creek Dam on the Rogue River is best represented at the "at Dodge Bridge" gaging station (Figure 1) downstream of the confluence of the Rogue River and Elk Creek. Table 17 presents results for the 10-year average of mean monthly suspended sediment concentrations for all scenarios at the "at Dodge Bridge" station. Comparison of scenarios 4 and 5 (Elk Creek dam operating at full or minimum pool) with scenario 2 (Lost Creek Dam operating only) showed slightly decreased suspended sediment concentrations at the "Dodge Bridge" gaging station for most of the year. Minimal increases (less than 1 mg/ℓ) occurred during summer months for scenarios 4 and 5, probably because both project flows from Elk Creek Dam were increased from predam conditions. In addition, suspended sediment concentrations in the releases were also increased for each scenario, causing slight increases of suspended sediment concentrations in the Rogue River. However, increases in suspended sediment concentrations were well within the range of the predictions. Yearly suspended sediment results for predam (solid line) and postdam conditions (dashed line represents scenario 2, crosses represent scenario 4, and squares represent scenario 5) at the "at Dodge Bridge" station for 1981, 1984, and 1986 are presented in Figures 35-37, respectively. Note that during high-flow seasons, operation of Elk Creek Dam, in general, reduced suspended sediment concentrations at the "at Dodge Bridge" station (Figures 35-37) as compared to scenarios without Elk Creek Dam.

110. The impacts of operation of Applegate Dam on the immediate tailwater of the Applegate River at the "near Copper" gaging station (Figure 1) are presented in Table 18. Operation of Applegate Dam, in general, decreased suspended sediment concentrations on the Applegate River at the "near Copper" station for most of the year. This can also be seen in

Table 17

Ten-Year Average of Predicted Mean Monthly Suspended Sediment Concentrations at the "Rogue River at Dodge Bridge" Gaging Station

Scenario	10-Year Average of Mean Monthly SS Concentrations, mg/ℓ											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	11.9	23.0	11.7	13.1	20.5	10.2	3.9	2.9	2.5	6.78	7.78	20.00
2	8.4	16.1	8.2	5.4	3.5	3.1	2.6	2.3	2.1	4.00	4.67	12.78
3	8.4	16.1	8.2	5.4	3.5	3.1	2.6	2.3	2.1	4.00	4.67	12.78
4	6.2	14.4	7.4	5.1	3.7	3.2	3.2	3.1	2.5	3.00	3.89	11.10
5	6.2	13.9	7.9	5.6	3.7	3.3	2.8	2.4	2.1	3.00	4.00	10.78

Table 18

Ten-Year Average of Predicted Mean Monthly Suspended Sediment Concentrations at the "Applegate near Copper" Gaging Station

Scenario	10-Year Average of Mean Monthly SS Concentrations, mg/ℓ											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	25.00	62.6	21.8	9.6	23.4	12.6	3.6	2.5	2.2	3.2	16.6	84.9
2	25.00	62.6	21.8	9.6	23.4	12.6	3.6	2.5	2.2	3.2	16.6	84.9
3	7.70	10.4	5.7	4.2	3.2	2.8	2.3	2.7	2.5	3.2	3.4	14.7
4	7.70	10.4	5.7	4.2	3.2	2.8	2.3	2.7	2.5	3.2	3.4	14.7
5	7.70	10.4	5.7	4.2	3.2	2.8	2.3	2.7	2.5	3.2	3.4	14.7

Figures 38-40, which show yearly suspended sediment results for predam (solid line) and postdam (dotted line) conditions at the "near Copper" station for 1981, 1984, and 1986, respectively. Note that the postdam suspended sediment concentrations are difficult to see on the figures because of the substantial differences in suspended sediment concentrations for predam and postdam conditions.

111. The impact of operation of Applegate Dam on suspended sediment concentrations in the Rogue River is best represented at the "at Merlin" gaging station, which is downstream of the confluence of the Rogue and Applegate Rivers. Table 19 presents the 10-year average of predicted mean monthly suspended sediment concentrations for all scenarios at the "at Merlin" station. Generally, operation of Applegate Dam (scenario 3), when compared to scenario 2, reduced suspended sediment concentrations for all months at the "at Merlin" station (Table 19). Yearly suspended sediment results at the "at Merlin" station for 1981, 1984, and 1986, are presented in Figures 41-43, respectively. The impact of Applegate Dam operations on suspended sediment concentrations in the Rogue River was most evident during high flows, such as occurred on Julian day 353 (1981) when suspended sediment released from Applegate was reduced from 8,984 mg/ℓ (predam conditions) to 233 mg/ℓ. This, in turn, substantially reduced the suspended sediment concentration at the "at Merlin" station from 1,500 mg/ℓ predam and 1,700 mg/ℓ with Lost Creek only to 500 mg/ℓ.

112. Changes in suspended sediment concentrations versus distance from Lost Creek and Applegate Dams (Table 5) were examined during high- and low-flow time periods on the Rogue and Applegate Rivers for all five scenarios. February and December were chosen to represent high-flow months; June and September were chosen to represent low-flow months.

113. On the Rogue River, suspended sediment concentrations were examined at the following stations for predam and postdam conditions: "at McLeod," "at Dodge Bridge," and "at Merlin." For both high-flow months, suspended sediment concentrations were reduced at the "at McLeod" station from predam conditions, and increased downstream with distance from Lost Creek Dam (Table 20). Suspended sediment concentration increases were caused by loadings from tributaries. Tributary contributions were more evident on the Rogue River for high-flow months when projects were operating as compared to predam conditions (Table 20). For the dry season months, suspended sediment

Table 19

Ten-Year Average of Predicted Mean Monthly Suspended Sediment Concentrations at the "Rogue at Merlin" Gaging Station

Scenario	10-Year Average of Mean Monthly SS Concentrations, mg/ℓ											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	20.2	49.3	22.2	20.2	22.6	11.1	4.4	3.6	3.3	6.78	11.10	49.40
2	18.8	48.9	20.9	15.9	13.1	5.8	3.2	2.9	2.8	4.44	9.10	47.10
3	14.7	41.4	19.6	15.4	8.8	4.1	3.2	2.9	2.7	4.44	6.89	34.40
4	13.9	42.0	19.7	15.7	8.8	4.1	3.6	3.4	2.9	3.89	6.67	33.89
5	14.0	40.6	19.4	15.5	8.9	4.1	3.3	2.9	2.7	3.89	6.89	33.67

Table 20

Suspended Sediment Concentrations (mg/ℓ) Along the Rogue River Using the 10-Year Average of Mean Monthly Data for High- and Low-Flow Months

Gaging Station	Month	Scenario				
		1	2	3	4	5
at McLeod	February	20.4	3.2	3.2	3.2	3.2
at Dodge Bridge	February	23.0	16.1	16.1	14.4	13.9
at Merlin	February	49.3	48.9	41.4	42.0	40.6
at McLeod	December	18.0	2.8	2.8	2.8	2.8
at Dodge Bridge	December	20.0	12.8	12.8	11.1	10.8
at Merlin	December	49.4	47.7	34.4	33.9	33.7
at McLeod	June	10.9	3.0	3.0	3.0	3.0
at Dodge Bridge	June	10.2	3.1	3.1	3.2	3.2
at Merlin	June	11.1	5.8	4.1	4.1	4.1
at McLeod	September	2.0	1.6	1.6	1.6	1.6
at Dodge Bridge	September	2.5	2.1	2.1	2.5	2.1
at Merlin	September	3.3	2.8	2.7	2.9	2.7

concentrations were also reduced at the "at McLeod" station. However, tributary loadings were not very significant as compared to high-flow months.

114. Suspended sediment concentrations on the Applegate River were examined at the following stations for predam and postdam conditions: "near Copper," "at Applegate," and "near Wilderville." As was the case for Lost Creek Dam, suspended sediment concentrations were reduced at the "near Copper" station from predam conditions for high-flow months. Concentrations also increased down the Applegate River to the "near Wilderville" station (Table 21) during high-flow months. These increases were again the result of loadings from major tributaries influencing the Applegate River. Tributary contributions were more evident when Applegate Dam was operating as compared to predam conditions (Table 21). Suspended sediment concentrations during June were reduced with Applegate operating; however, during September, there was a slight increase in concentration at the "near Copper" station (Table 21). Tributary contributions during low-flow months were barely detectable on the Applegate River.

Turbidity

115. With the completion of the suspended sediment simulations, relationships from Table 4 were used to convert suspended sediment concentrations to equivalent turbidity values at index stations in the Rogue River Basin. Conversion relationships of suspended sediments (mg/ℓ) to turbidity (JTU) at index stations are illustrated in Figures 44a-d.

116. Suspended sediment concentrations converted to equivalent turbidity values at the "at McLeod" station was a linear relationship; thus, turbidity values during each year behaved similar to suspended sediment concentrations. For example, a decrease or increase in suspended sediment concentrations produced the same behavior in equivalent turbidity values. This relationship is shown in Figure 44a. Conversion of suspended sediment to turbidity at the "near Trail" station was a slightly nonlinear relationship (Table 4). Equivalent turbidity values using the nonlinear relationship at the "near Trail" station are shown in Figure 44b. Turbidity values converted from suspended sediment concentrations at the "at Dodge Bridge" station was a linear relationship (Table 4). Two linear relationships were used for the

Table 21

Changes in Suspended Sediment Concentrations (mg/ℓ) Along the Applegate River Using the 10-Year Average of Mean Monthly Data for High- and Low-Flow Months

Gaging Station	Month	Scenario 1	2	3	4	5
near Copper	February	62.6	62.6	10.4	10.4	10.4
at Applegate	February	68.5	68.5	25.2	25.2	25.2
near Wilderville	February	74.0	74.0	54.0	54.0	54.0
near Copper	December	84.9	84.9	14.9	14.9	14.9
at Applegate	December	78.4	78.4	31.1	31.1	31.1
near Wilderville	December	76.7	76.7	47.4	47.4	47.4
near Copper	June	12.6	12.6	2.8	2.8	2.8
at Applegate	June	10.7	10.7	3.4	3.4	3.4
near Wilderville	June	10.1	10.1	2.9	2.9	2.9
near Copper	September	2.2	2.2	2.5	2.5	2.5
at Applegate	September	1.8	1.8	2.2	2.2	2.2
near Wilderville	September	1.7	1.7	2.1	2.1	2.1

turbidity conversion for two ranges of suspended sediment concentrations: 0 to <15 mg/ℓ, and ≥15 mg/ℓ.

117. Figure 44c shows these relationships plotted for increasing suspended sediment concentrations. Some examples of converted turbidity values for the two ranges of suspended sediment concentrations were 1.73 and 49.32 JTU, corresponding to suspended sediment concentrations of 1 and 100 mg/ℓ, respectively. Conversion of turbidity from suspended sediment concentrations at the "near Copper" station was a nonlinear relationship (Table 4) for predam conditions. Two nonlinear relationships were used for the turbidity conversion for two ranges of suspended sediment concentrations: 0 to <45 mg/ℓ, and ≥45 mg/ℓ. For postdam conditions, a linear relationship (Table 4) was used to convert suspended sediment to turbidity. Predam relationships are illustrated in Figure 44d.

118. The impacts of operation of Lost Creek Dam on turbidity in the immediate tailwater of the Rogue River at the "at McLeod" gaging station (Figure 1) are presented in Table 22. In general, operation of Lost Creek Dam decreased turbidity at the "at McLeod" station for all months (Table 22). Yearly turbidity results for predam (solid line) and postdam (dashed line)

Table 22

Ten-Year Average of Converted Mean Monthly Turbidity Values at the "at McLeod" Gaging Station

Scenario	10-Year Average of Monthly Turbidity Values, JTU											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	3.6	6.0	[illegible].4	4.3	6.5	3.7	2.2	2.0	1.8	2.8	2.8	5.3
2	2.3	2.6	[illegible].6	3.4	2.6	2.2	2.1	1.8	1.7	1.7	2.1	2.4
3	2.3	2.6	[illegible].6	3.4	2.6	2.2	2.1	1.8	1.7	1.7	2.1	2.4
4	2.3	2.6	[illegible].6	3.4	2.6	2.2	2.1	1.8	1.7	1.7	2.1	2.4
5	2.3	2.6	2.6	3.4	2.6	2.2	2.1	1.8	1.7	1.7	2.1	2.4

Table 23

Ten-Year Average of Converted Mean Monthly Turbidity Values at the Elk Creek "Near Trail" Gaging Station

Scenario	10-Year Average of Monthly Turbidity Values, JTU											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	9.0	13.6	7.4	5.2	2.2	0.7	0.9	0.6	0.9	5.1	7.3	10.7
2	9.0	13.6	7.4	5.2	2.2	0.7	0.9	0.6	0.9	5.1	7.3	10.7
3	9.0	13.6	7.4	5.2	2.2	0.7	0.9	0.6	0.9	5.1	7.3	10.7
4	9.1	10.2	10.6	9.6	8.4	8.3	7.8	7.1	7.3	7.0	9.1	9.4
5	9.9	10.7	10.5	9.8	8.6	8.5	7.7	7.5	8.3	9.3	10.6	9.0

conditions at the "at McLeod" station for 1981, 1984, and 1986 are presented in Figures 45-47, respectively. Note that turbidity for all years was decreased, especially during high-flow seasons.

119. The impacts of operation of Elk Creek Dam (at full and minimum pool) on turbidity in the immediate tailwater of Elk Creek are presented in Table 23 at the "near Trail" gaging station. Turbidity values for both operation scenarios were increased from predam conditions for most of the year (Table 23), similar to what occurred for suspended sediments at the "near Trail" station. Significant differences in turbidity between operation scenarios occurred in September, October, and November when minimum pool operation produced greater turbidity values. This was probably due to differences in release discharge rates for each scenario during this time of the year. Yearly turbidity results for predam and postdam conditions at the "near Trail" station for 1981, 1984, and 1986 are presented in Figures 48-50, respectively. Note that turbidity was substantially reduced during high-flow months.

120. The impact of operation of Elk Creek Dam on the Rogue River is best represented at the "at Dodge Bridge" gaging station (Figure 1), which is downstream of the confluence of the Rogue River and Elk Creek. Table 24 presents results for the 10-year average of converted mean monthly turbidity results for all scenarios at the "at Dodge Bridge" station. Comparison of scenarios 4 and 5 (Elk Creek Dam operating at full or minimum pool) with scenario 2 (Lost Creek Dam operating only) showed slightly decreased turbidity values at the "Dodge Bridge" gaging station for most of the year. Minimal increases (less than 1 JTU) occurred during summer months, probably because flows from both Elk Creek scenarios were increased from predam conditions. In addition, turbidity of releases was also increased for each scenario (Table 24), resulting in slight increases of turbidity in the Rogue River. Yearly turbidity results for predam and postdam conditions at the "at Dodge Bridge" station for 1981, 1984, and 1986 are presented in Figures 51-53, respectively. Note that, during high flows, operation of Elk Creek Dam usually reduced turbidity at the "at Dodge Bridge" station (Figures 51-53) as compared to scenarios without Elk Creek Dam.

121. The impacts of operation of Applegate Dam on the immediate tailwater of the Applegate River are presented in Table 25 at the "near Copper" gaging station (Figure 1). Operation of Applegate Dam, in general,

Table 24

Ten-Year Average of Converted Mean Monthly Turbidity Values

at the "Rogue River at Dodge Bridge" Gaging Station

Scenario	10-Year Average of Monthly Turbidity Values, JTU											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	8.8	14.2	8.8	9.8	13.1	7.4	3.8	3.0	2.7	5.3	6.6	12.4
2	6.5	11.0	6.6	5.1	3.7	3.3	3.1	2.8	2.5	3.8	4.2	8.3
3	6.5	11.0	6.6	5.1	3.7	3.3	3.1	2.8	2.5	3.8	4.2	8.3
4	5.5	9.8	6.2	5.0	3.8	3.4	3.4	3.2	2.8	3.3	4.0	7.6
5	6.9	13.2	7.4	6.5	5.6	3.7	3.2	2.9	2.7	3.6	4.4	9.3

decreased turbidity values on the Applegate River at the "near Copper" station (Table 25) for most of the year. Increases of turbidity (less than 1.2 JTU) were observed during fall and winter months. Yearly turbidity results for predam (solid line) and postdam (dotted line) conditions at the "near Copper" station for 1981, 1984, and 1986 are presented in Figures 54-56, respectively. Note that turbidity of releases (as in the case for Lost Creek and Elk Creek Dam) were substantially reduced.

122. Impact of Applegate Dam on turbidity in the Rogue River is best represented at the "at Merlin" gaging station, which is downstream of the confluence of the Rogue and Applegate Rivers. The same linear regression equation used to convert suspended sediment to turbidity at the "at Dodge Bridge" station was used for the conversion at the "at Merlin" station (Table 4 and Figure 44c). Table 26 presents the results for the 10-year average of converted mean monthly turbidity values for all scenarios at the "at Merlin" station. Operation of Applegate Dam (scenario 3) when compared to scenario 2 reduced turbidity for all months at the "at Merlin" station (Table 26). Yearly turbidity results for predam and postdam conditions at the "at Merlin" station for 1981, 1984, and 1986 are presented in Figures 57-59, respectively. Note that during high-flow seasons, turbidity at the "at Merlin" gaging station was, in general, reduced from predam conditions for all years.

Table 25

Ten-Year Average of Converted Mean Monthly Turbidity Values at the Applegate River "Near Copper" Gaging Station

Scenario	10-Year Average of Monthly Turbidity Values, JTU											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	6.3	13.8	6.5	4.3	8.0	4.9	1.6	1.2	1.0	1.2	5.6	12.4
2	6.3	13.8	6.5	4.3	8.0	4.9	1.6	1.2	1.0	1.2	5.6	12.4
3	6.7	9.4	4.7	3.1	2.1	1.7	1.2	1.5	1.3	2.3	2.4	13.6
4	6.7	9.4	4.7	3.1	2.1	1.7	1.2	1.5	1.3	2.3	2.4	13.6
5	6.7	9.4	4.7	3.1	2.1	1.7	1.2	1.5	1.3	2.3	2.4	13.6

Table 26

Ten-Year Average of Converted Mean Monthly Turbidity Values at the "Rogue at Merlin" Gaging Station

Scenario	10-Year Average of Monthly Turbidity Values, JTU											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	13.0	26.2	14.7	13.6	14.2	8.1	4.3	3.7	3.4	5.6	8.4	25.3
2	12.1	25.9	14.1	11.3	8.9	5.0	3.4	3.1	2.9	4.1	7.0	23.9
3	10.4	22.7	13.4	11.0	6.7	3.9	3.4	3.0	2.8	4.0	5.9	18.8
4	10.0	22.9	13.6	11.0	6.8	3.9	3.6	3.3	3.1	3.8	5.8	18.4
5	9.8	22.3	13.6	11.1	6.9	4.0	3.4	3.0	2.9	3.8	5.9	18.4

PART IX: CONCLUSIONS OF RIVERINE SIMULATIONS

Temperature

123. The temperature simulations performed on the Rogue River Basin for the five scenarios produced the following conclusions:

a. Operation of each project had similar impacts to the immediate tailwater directly below the dams. Release water temperatures were, in general, increased during fall and winter months and decreased during spring and summer months. In addition, variations in monthly minimum and maximum release temperatures were reduced.

b. Operation of Lost Creek Dam had the greatest impact on water temperatures of the Rogue River, as compared with the other projects in the basin, because Lost Creek Dam is an impoundment located on the main stem Rogue River that directly affects flows and temperatures. Comparison of results from scenario 1 (predam) to those from scenario 2 (operating only Lost Creek) showed that water temperatures were influenced as far downstream as the "at Marial" gaging station (Figure 1), located 108 miles downstream of Lost Creek Dam.

c. Cumulative impacts resulting from the operation of all three projects in the Rogue River Basin showed that Elk Creek Dam and Applegate Dam had minimal impacts (temperature decreased less than 0.7° C at the "at Merlin" station during the summer) to Rogue River water temperatures as compared to operating Lost Creek Dam only (Table 14). Flows from these two projects would have to be much greater than flows at the confluence junction to the Rogue River to significantly influence water temperatures on the Rogue River.

Suspended Sediment

124. The suspended sediment simulations performed on the Rogue River Basin for the five scenarios produced the following conclusions:

a. In general, suspended sediment concentrations released from all projects were reduced from predam conditions except at Elk Creek Dam during summer months. Elk Creek suspended sediment concentrations for both operations (full and minimum pool) were higher during the summer period (Table 16). However, increases in suspended sediment concentrations at Elk Creek had minimal impact on suspended sediment concentration in the Rogue River (Table 17). Increases in suspended sediment concentrations in the Rogue River (less than 1 mg/ℓ) were barely detectable. Also, Rogue River suspended sediments were decreased by Elk Creek Dam operations during high-flow events (Figure 36).

b. Applegate Dam operations had a greater influence on Rogue River suspended sediment concentrations than Elk Creek Dam had. In general, Applegate Dam decreased suspended sediment concentrations for all months at the "at Merlin" station (Table 19).

c. Suspended sediment concentration, in general, increased with distance from Lost Creek and Applegate Dams (Tables 20 and 21) since project operations reduced suspended sediment releases coming from these projects. Increases along the Rogue and Applegate Rivers were due to loadings from major tributaries. Elk Creek has no major tributaries between the damsite and the junction to the Rogue River.

Turbidity

125. Conversion of suspended sediments to turbidity on the Rogue River Basin for the five scenarios produced the following conclusions:

a. In general, turbidity releases from all projects were reduced from predam conditions except at Elk Creek Dam during summer months. Elk Creek turbidity for both operations (full and minimum pool) was higher during the summer period (Table 22). However, increases in turbidity on Elk Creek had minimal impact on turbidity in the Rogue River. Increases in turbidity in the Rogue River (less than 1 JTU) were barely detectable. Also, Rogue River turbidities were decreased by Elk Creek Dam operations during high-flow events (Figure 52).

b. Applegate Dam operations had a greater influence on Rogue River turbidity than Elk Creek Dam had. In general, Applegate Dam decreased turbidity for all months (Table 25).

REFERENCES

Eiker, E. E. 1977. "Heat Exchange Program," Thermal Simulations of Lakes, Publication No. 65-902, Edison Electric Institute, New York, NY.

Environmental Laboratory. 1982. "CE-QUAL-R1: A Numerical One-Dimensional Model of Reservoir Water Quality; User's Manual," Instruction Report E-82-1 (Rev. ed., supersedes IR E-82-1 dated April 1982), US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Freeze, R. Allan, and Cherry, John A. 1979. Groundwater, Prentice-Hall, Englewood Cliffs, NJ.

Hamlin, Dorothy E., and Nestler, John M. 1987. "Development of a Model to Predict Longitudinal Water Temperatures for the Rogue River, Oregon," Miscellaneous Paper EL-87-15, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Harris, D. D. 1970. "Water-Surface Elevations and Channel Characteristics for Selected Reaches of the Rogue River and Elk Creek, Jackson and Josephine Counties, Oregon," US Geological Survey Open-File Report, Portland, OR.

Hydrologic Engineering Center, US Army Corps of Engineers. 1986. "Appendix on Water Quality Analysis; Exhibit 4: Program WEATHER User's Manual," Davis, CA.

Johnson, L. S., and Ford, D. E. 1981. "Verification of a One-Dimensional Reservoir Thermal Model," paper presented to conference of American Society of Civil Engineers, St. Louis, MO.

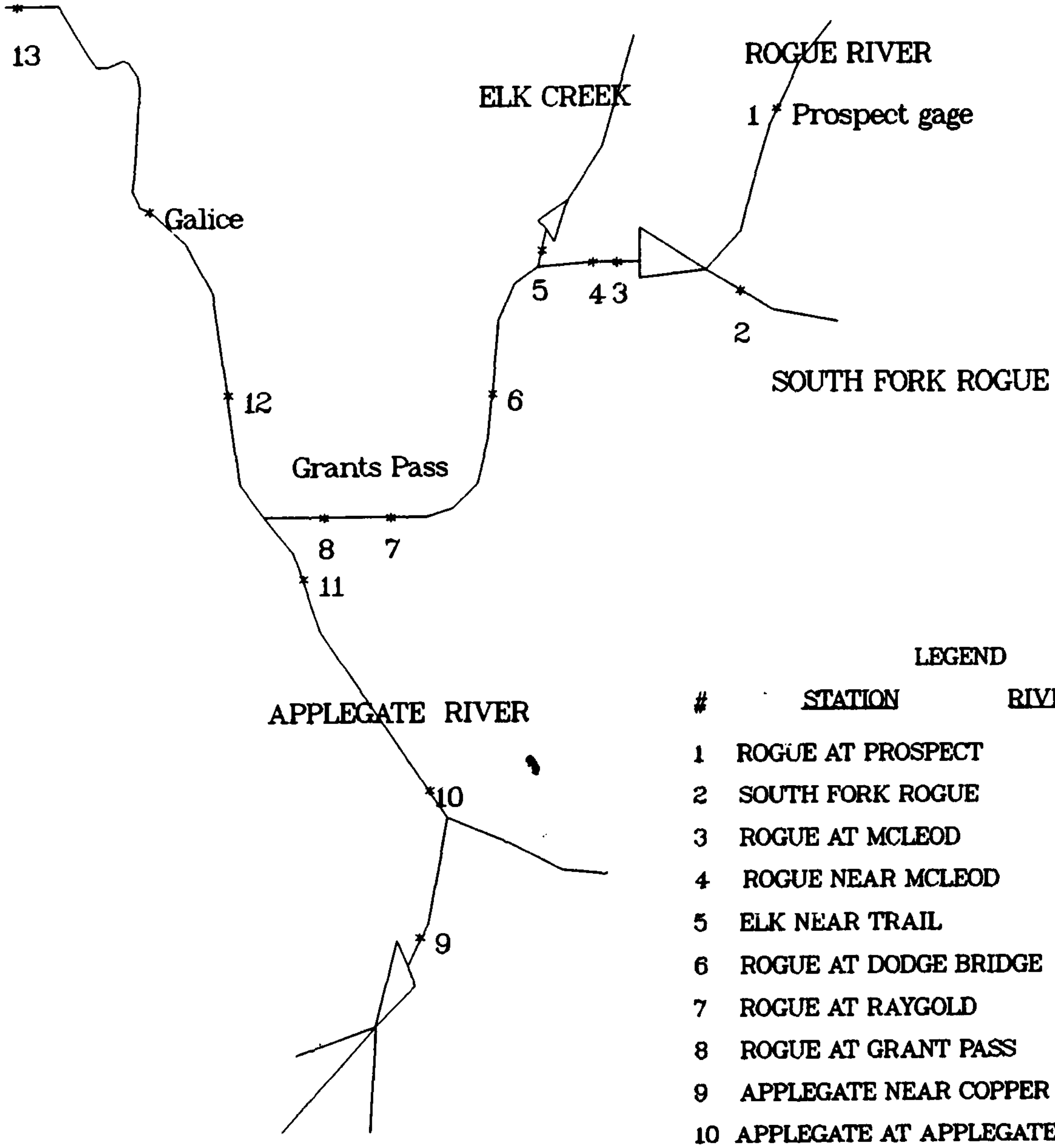
Larson, Arthur G., Wooldridge, David D., and Wald, Alan R. 1976. "Turbidity-Suspended Sediment Relations in Forest Streams of the Western Olympics," Final Report, Part II, College of Forest Resources, University of Washington, Seattle, WA.

Leggett, R. W., and Williams, L. R. 1981. "A Reliability Index for Models," Ecological Modeling, Vol 13, pp 303-312.

National Council of the Paper Industry for Air and Stream Improvement, Inc. 1982. "The Mathematical Water Quality Model QUAL-II and Guidance for Its Use - Revised Version," NCASI Technical Bulletin No. 391.

US Army Engineer District, Portland. 1974. "Rogue River Basin: Temperature and Turbidity," Vol 1 (Main Report) and Vol 2 (Appendices), Portland, OR.

__________. 1981. "Elk Creek Lake Environmental Impact Statement Supplement No. 1," Portland, OR.



LEGEND

#	STATION	RIVER MILES
1	ROGUE AT PROSPECT	169.4
2	SOUTH FORK ROGUE	2.4
3	ROGUE AT MCLEOD	157.4
4	ROGUE NEAR MCLEOD	154.3
5	ELK NEAR TRAIL	.3
6	ROGUE AT DODGE BRIDGE	138.7
7	ROGUE AT RAYGOLD	125.8
8	ROGUE AT GRANT PASS	101.9
9	APPLEGATE NEAR COPPER	46.6
10	APPLEGATE AT APPLEGATE	27.4
11	APPLEGATE AT WILDERVILLE	8.0
12	ROGUE AT MERLIN	86.7
13	ROGUE AT MARIAL	48.5

Figure 1. Rogue River Basin gaging stations

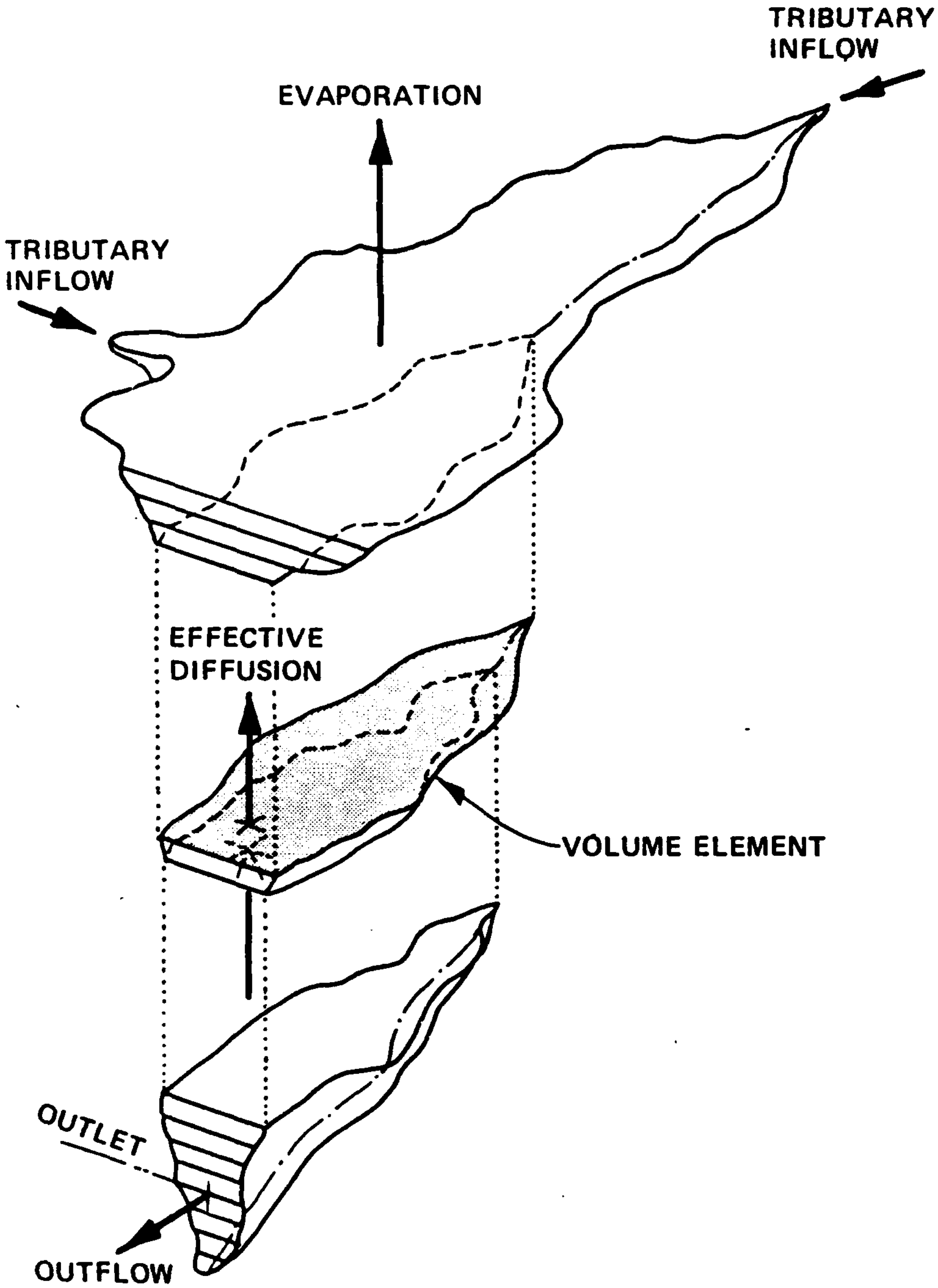


Figure 2. Geometric representation of a stratified reservoir and mass transport mechanisms

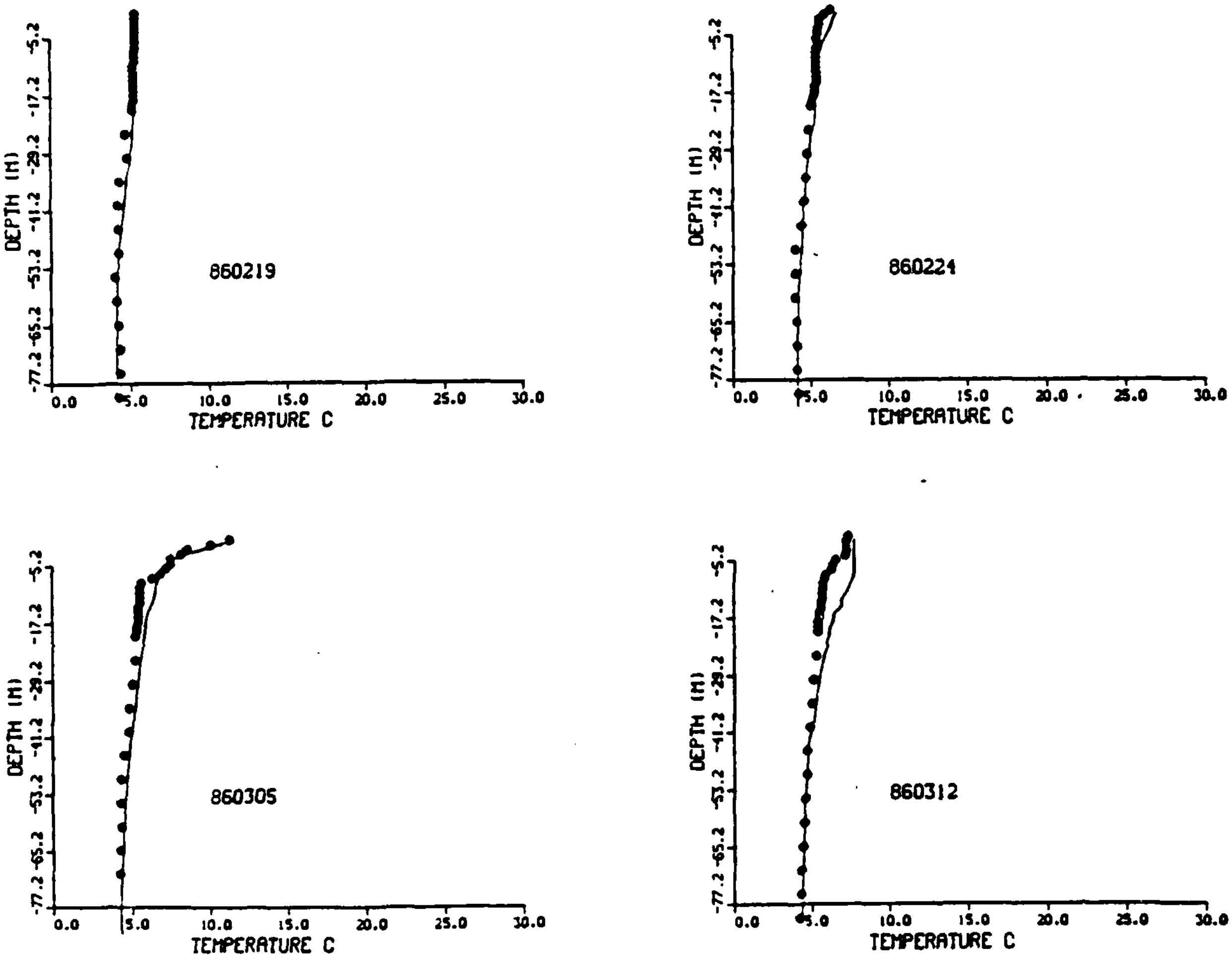


Figure 3. Predicted (--) and observed (...) calibration results, 1986, Lost Creek Dam (Sheet 1 of 8)

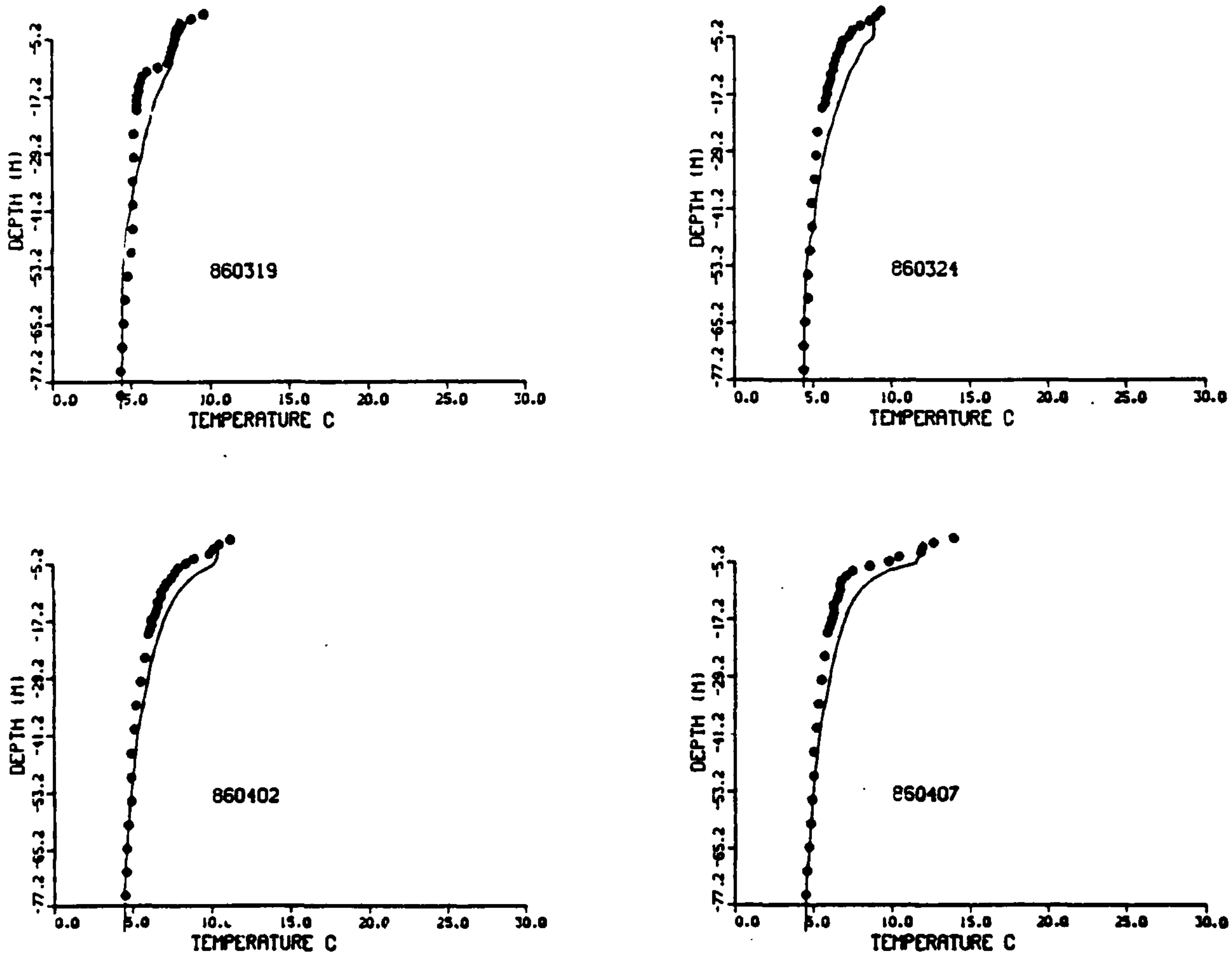


Figure 3. (Sheet 2 of 8)

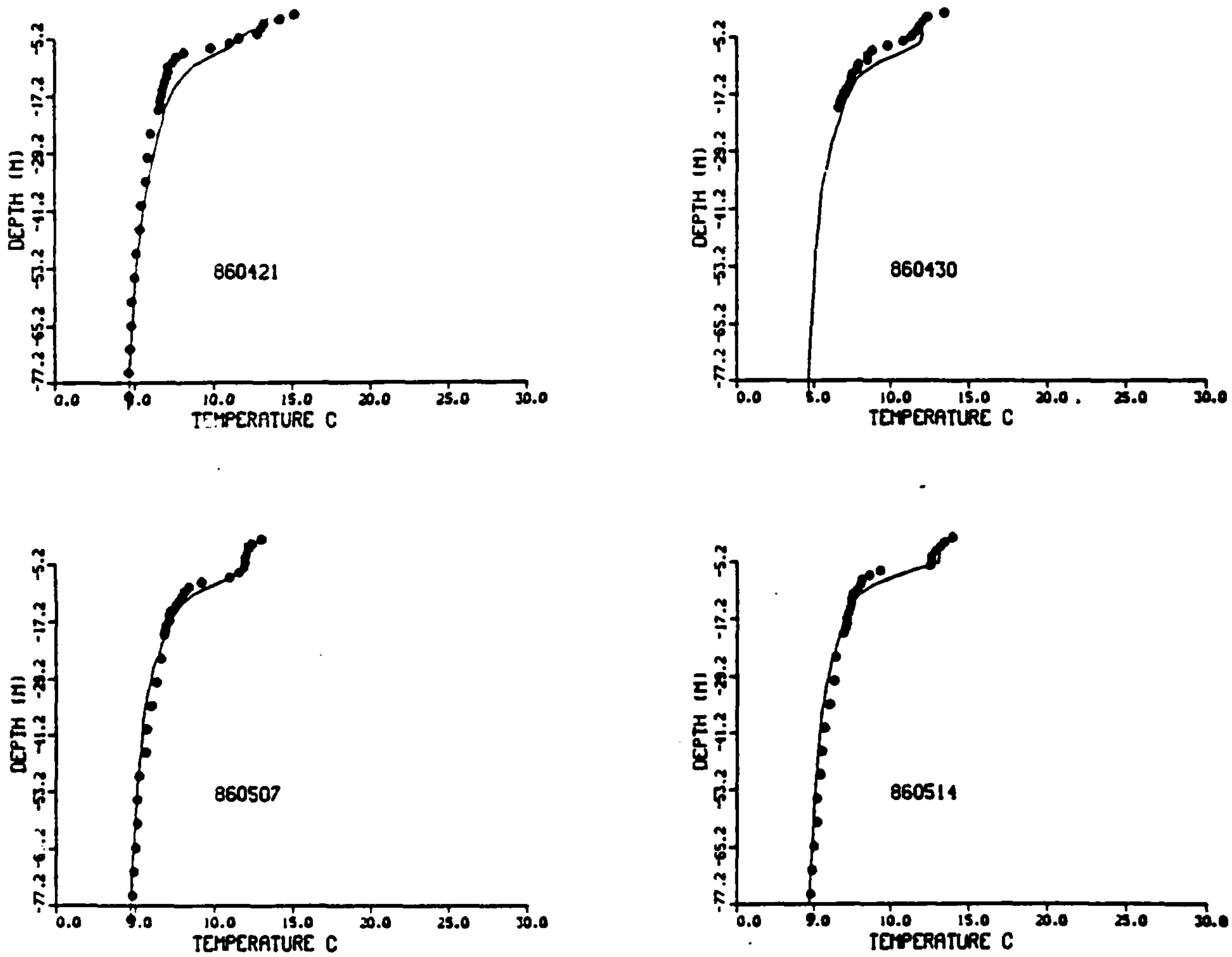


Figure 3. (Sheet 3 of 8)

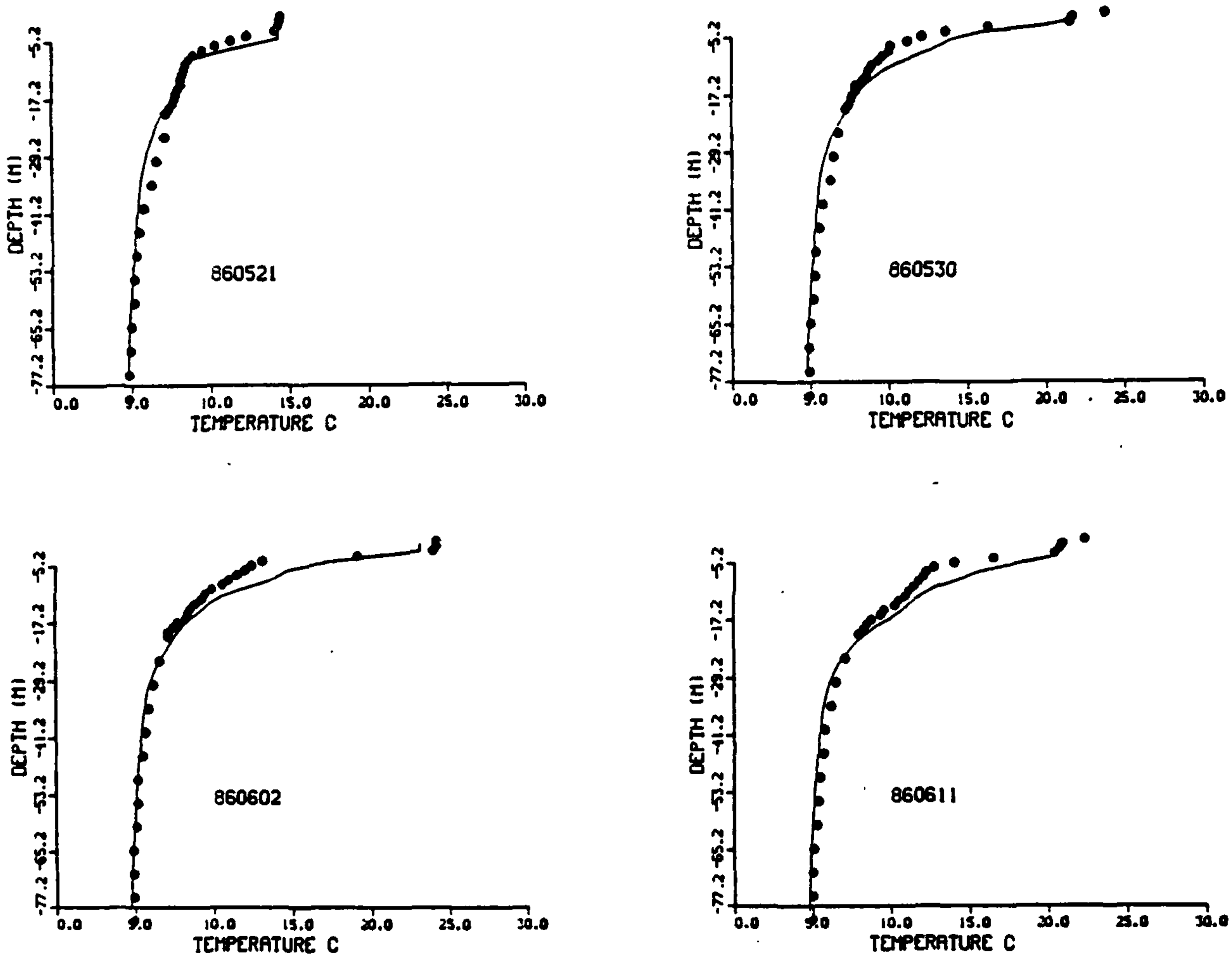


Figure 3. (Sheet 4 of 8)

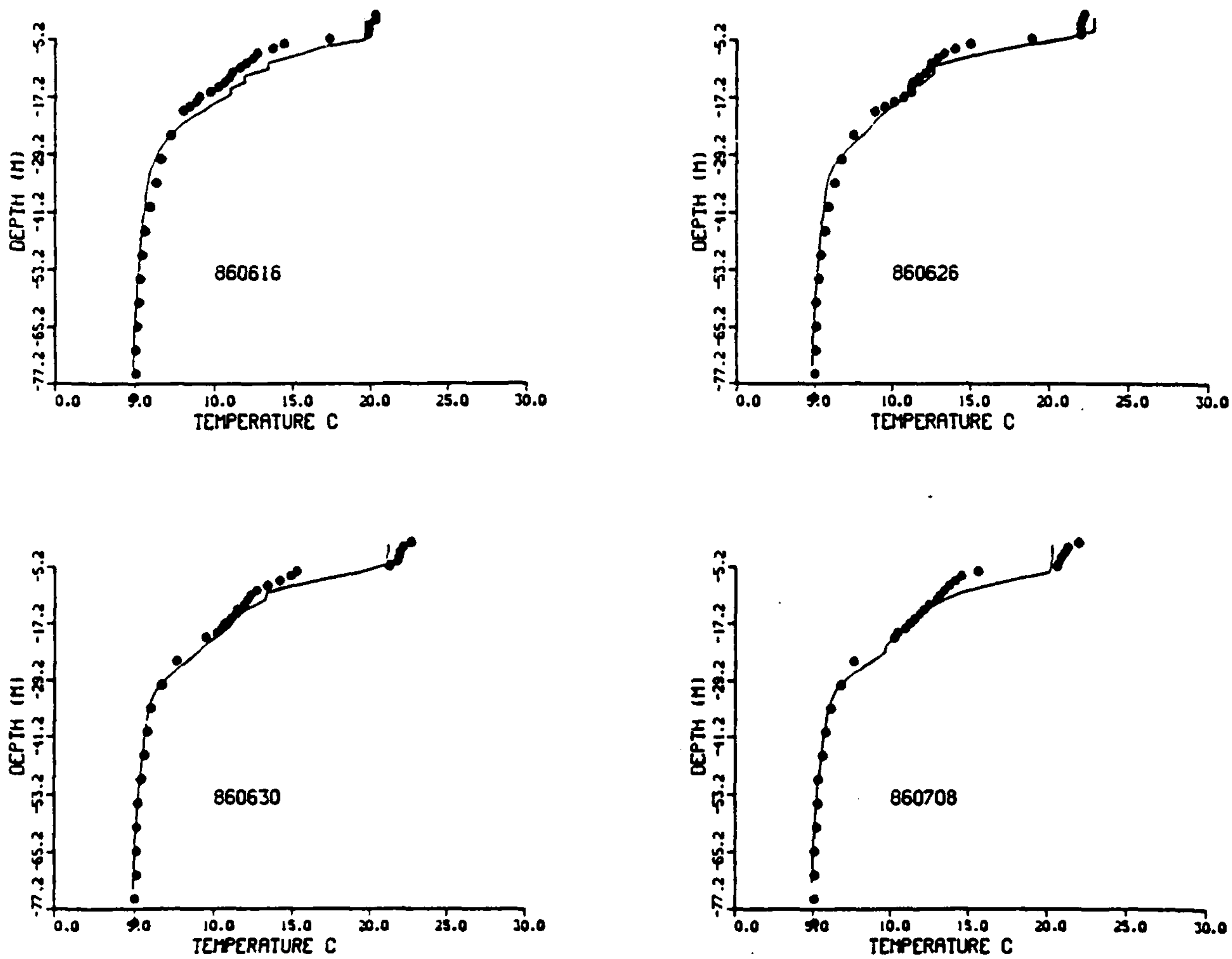


Figure 3. (Sheet 5 of 8)

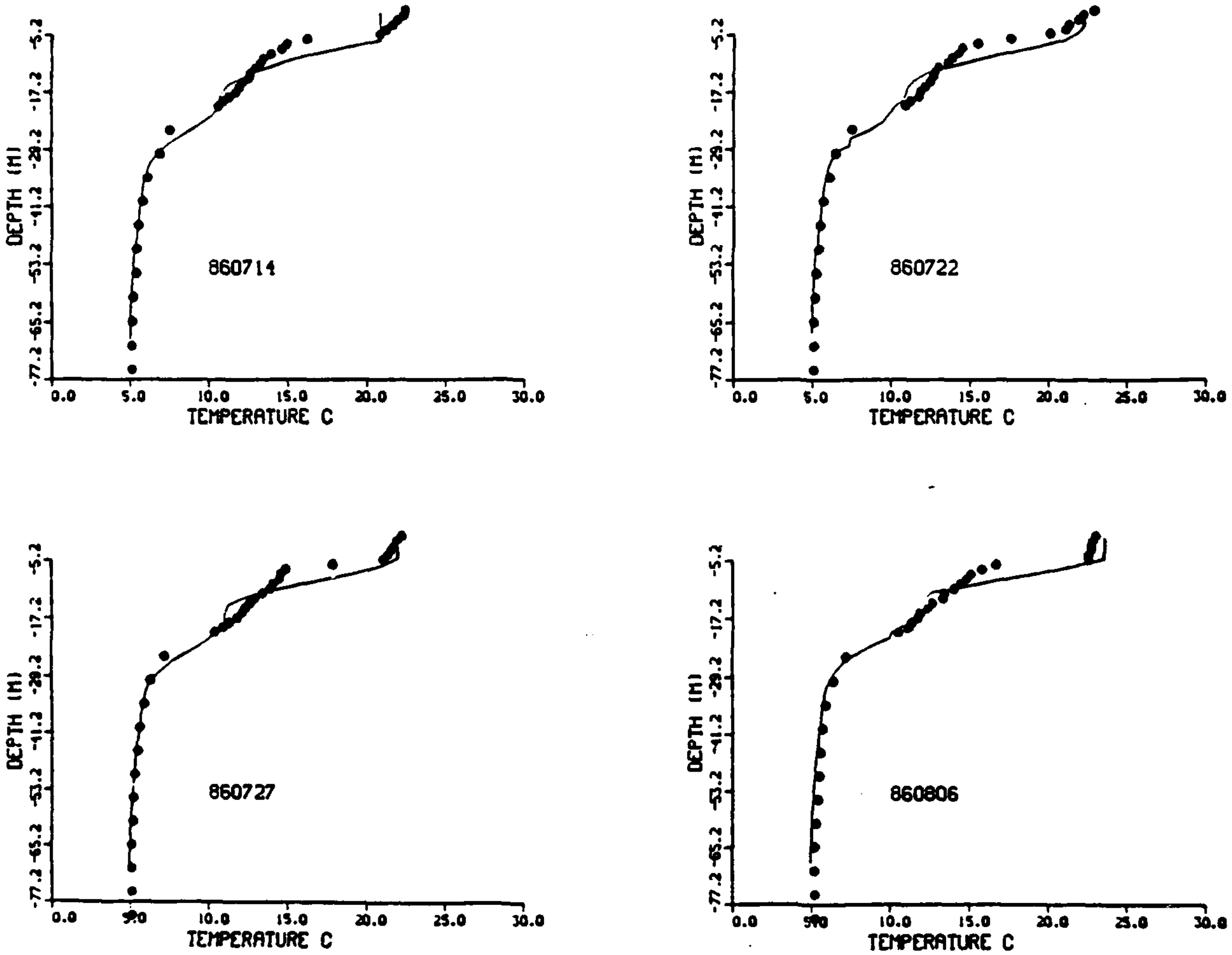


Figure 3. (Sheet 6 of 8)

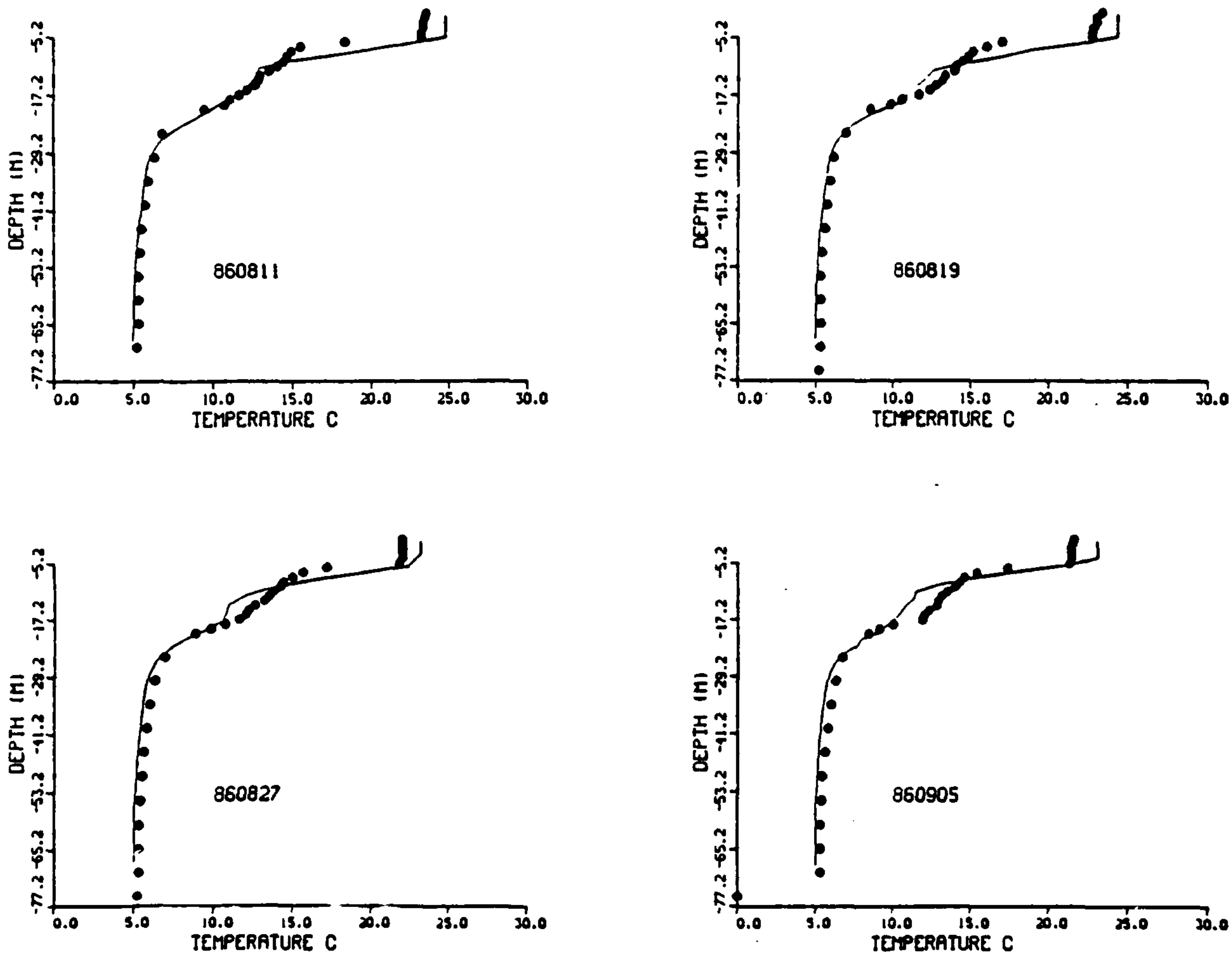


Figure 3. (Sheet 7 of 8)

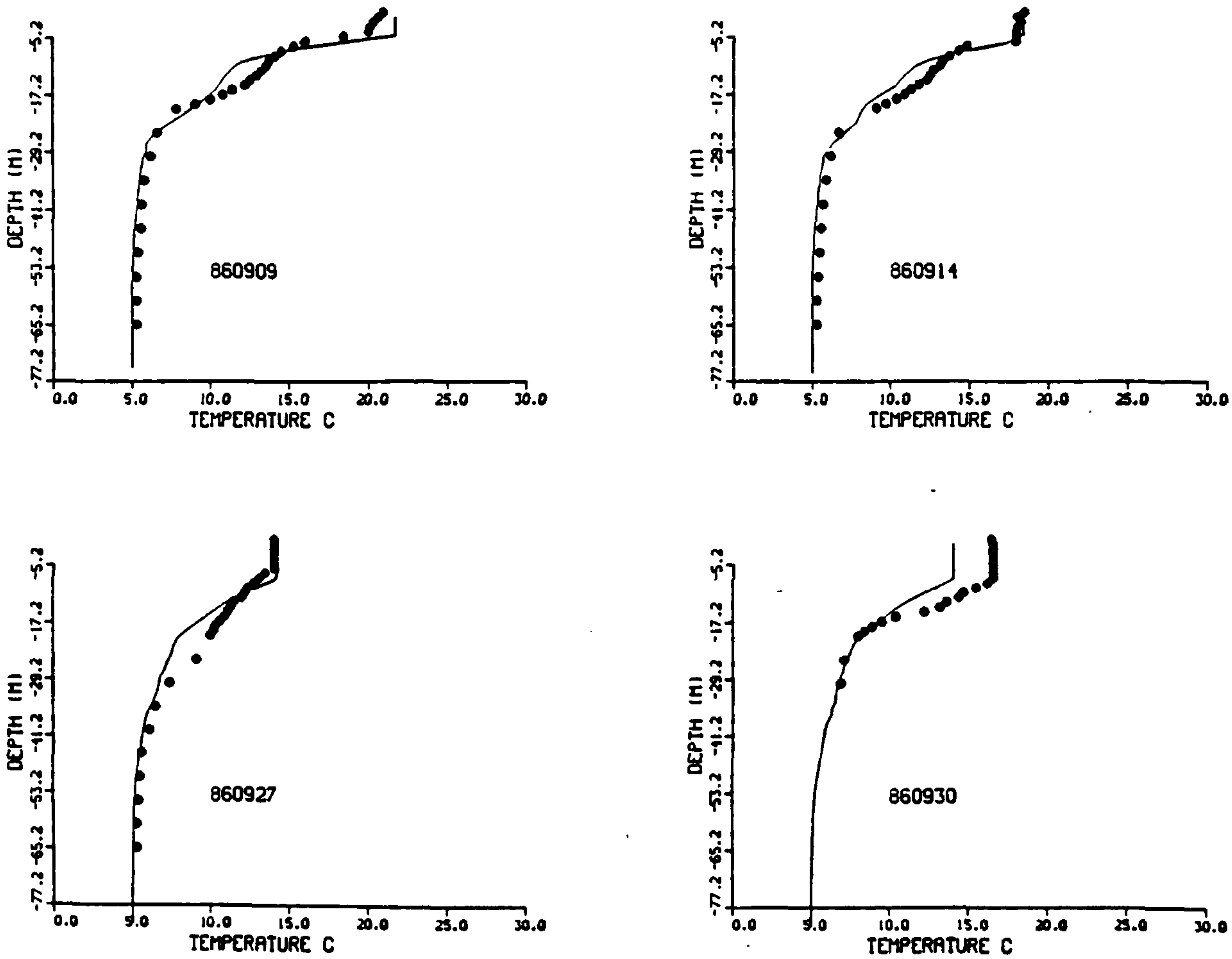


Figure 3. (Sheet 8 of 8)

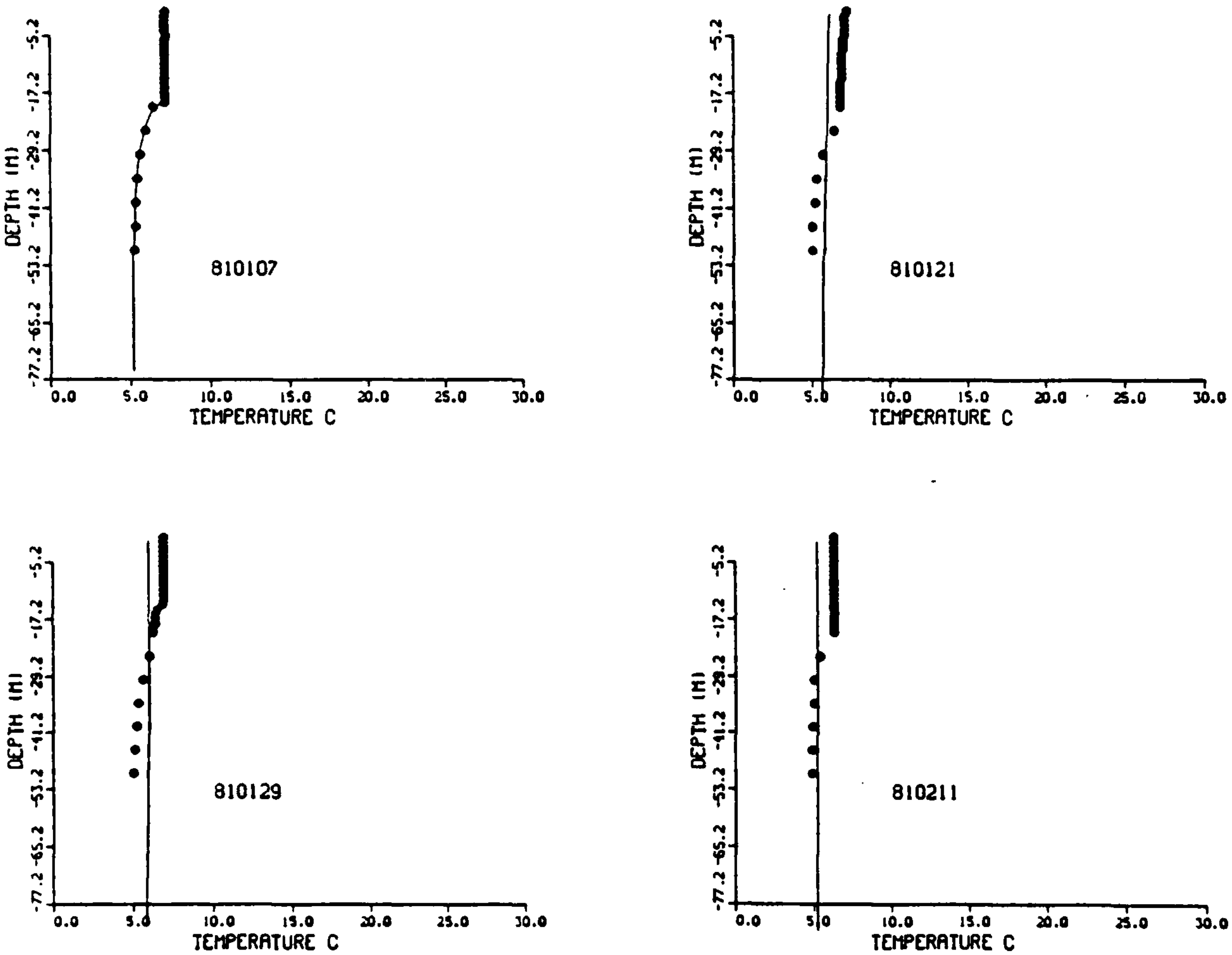


Figure 4. Predicted (--) and observed (...) verification results, 1981, Lost Creek Dam (Sheet 1 of 4)

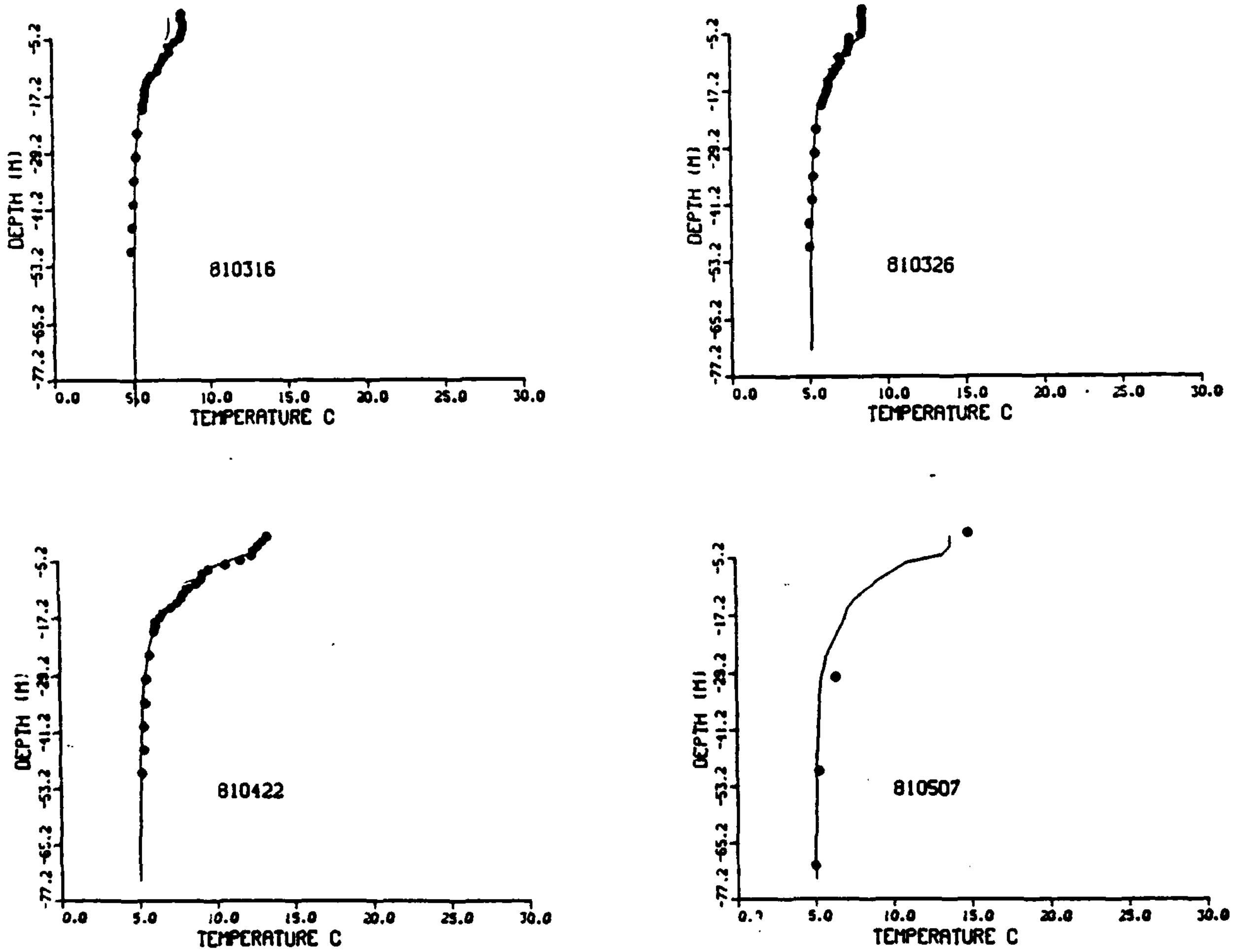


Figure 4. (Sheet 2 of 4)

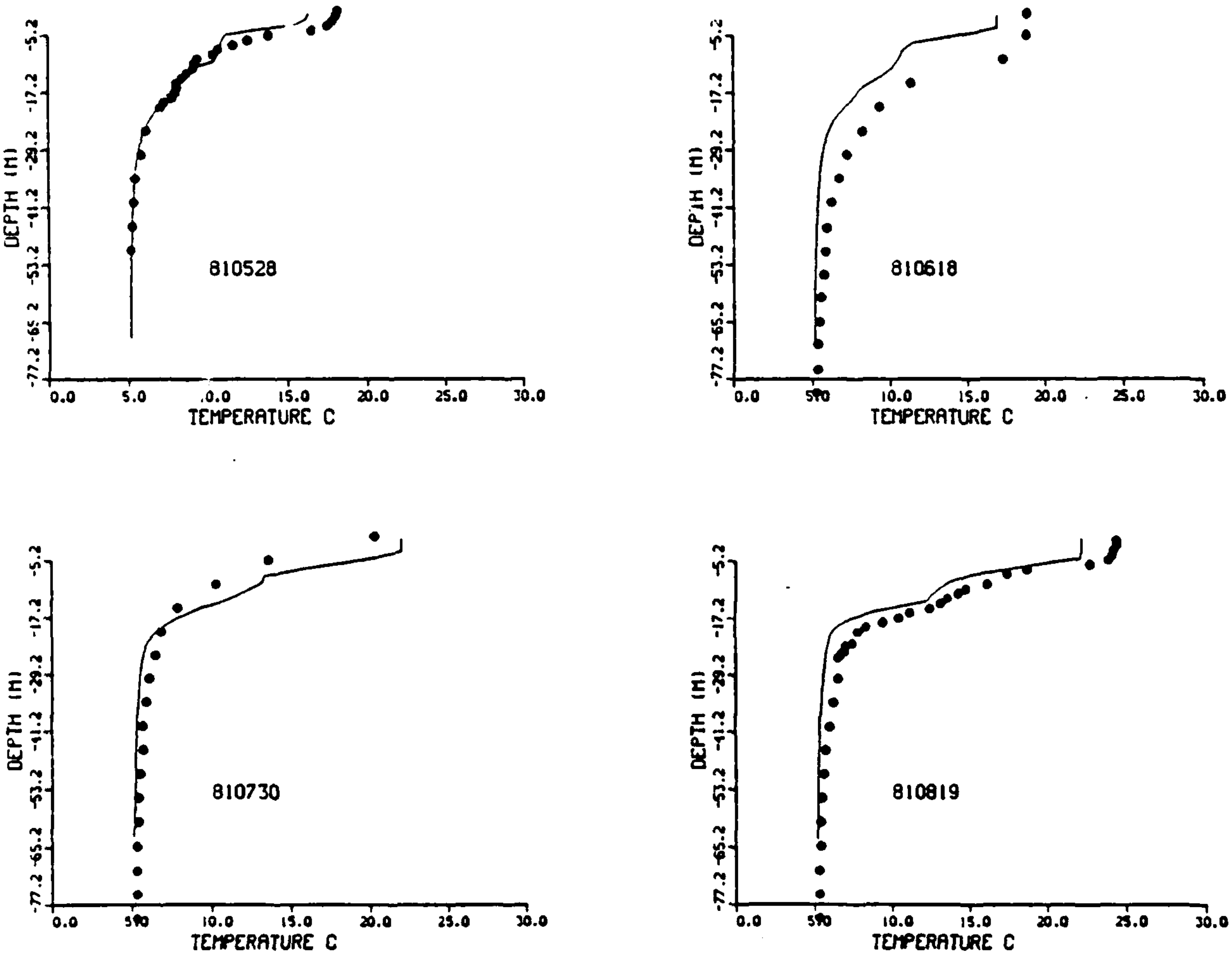


Figure 4. (Sheet 3 of 4)

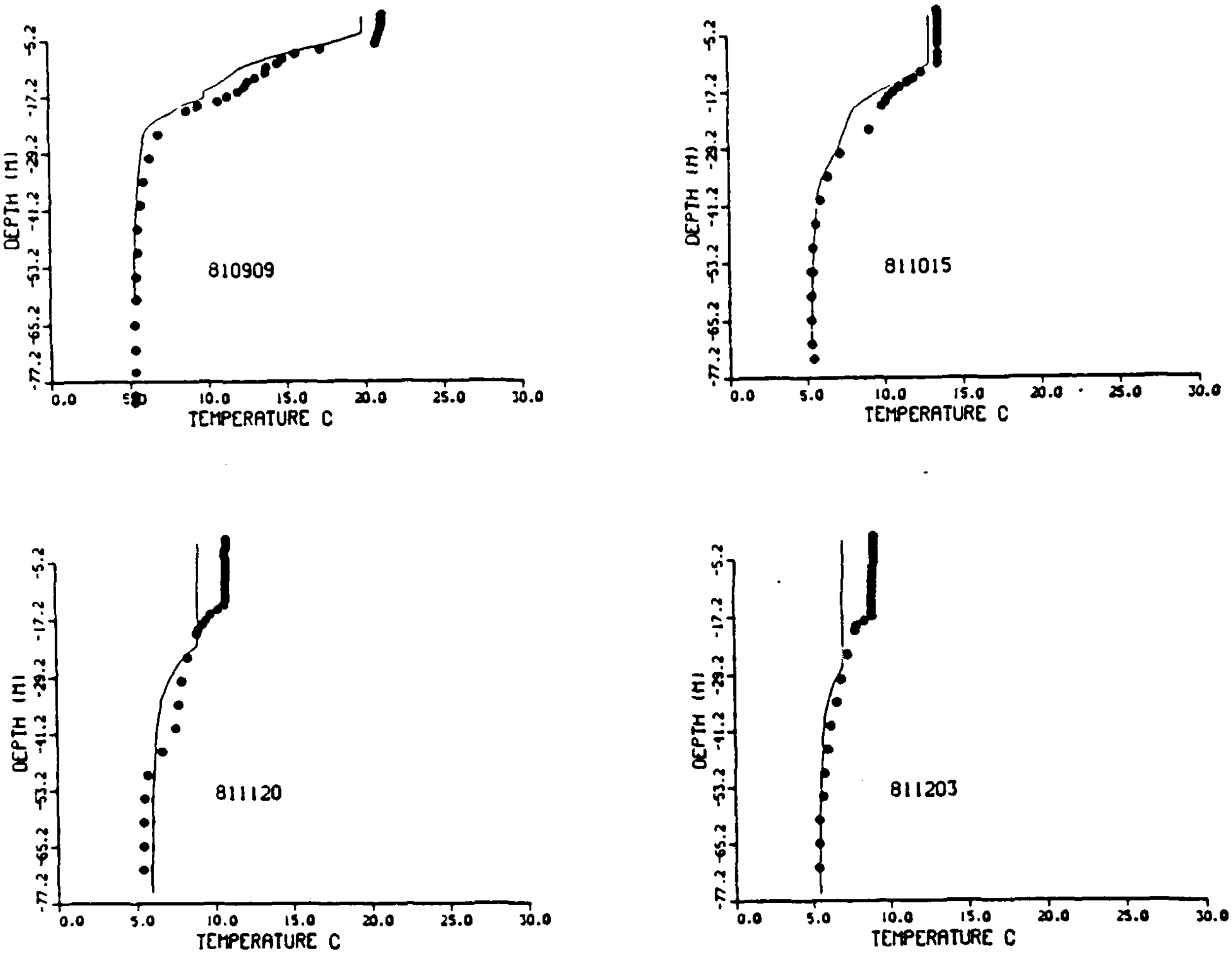


Figure 4. (Sheet 4 of 4)

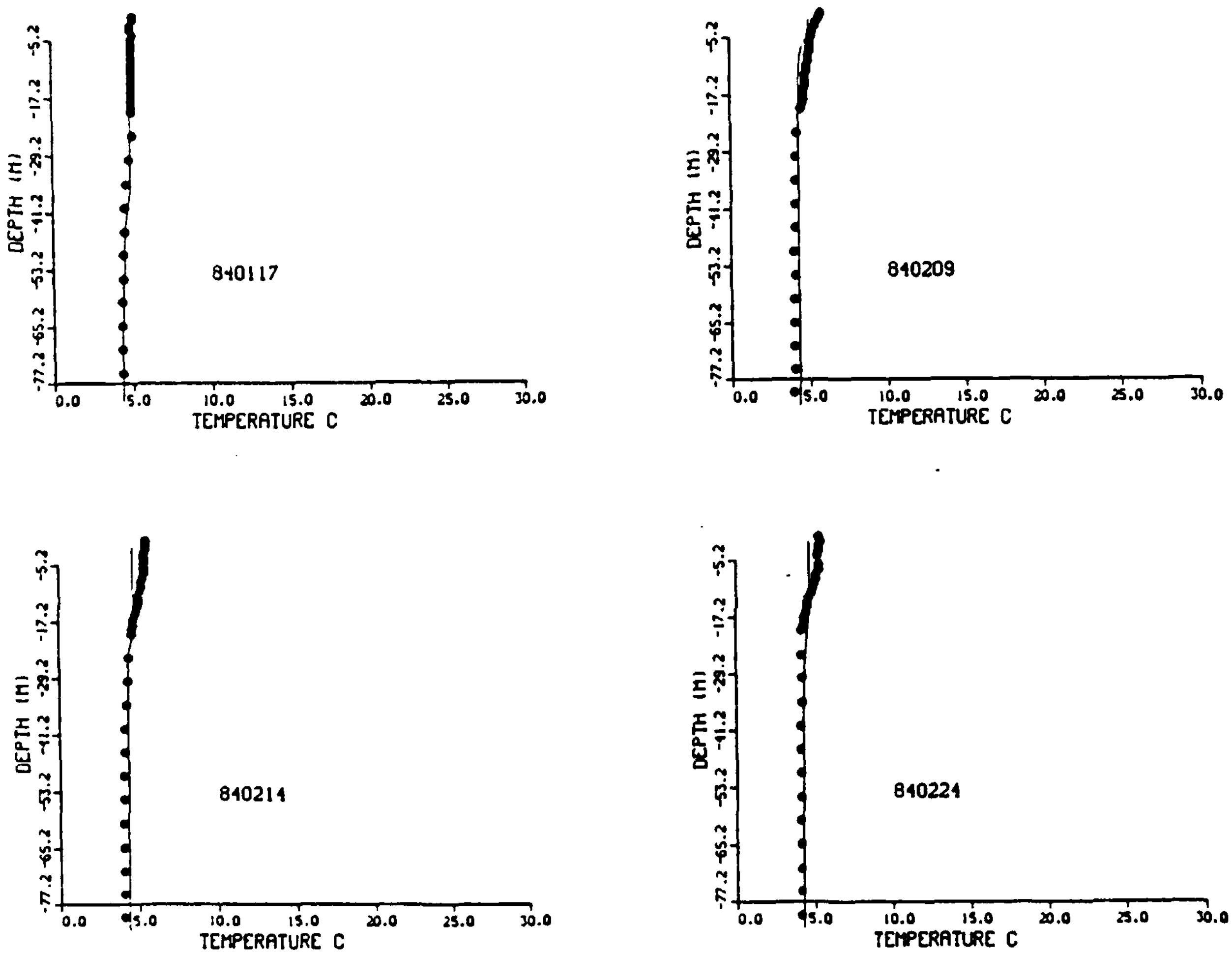


Figure 5. Predicted (---) and observed (...) verification results, 1984, Lost Creek Dam (Sheet 1 of 5)

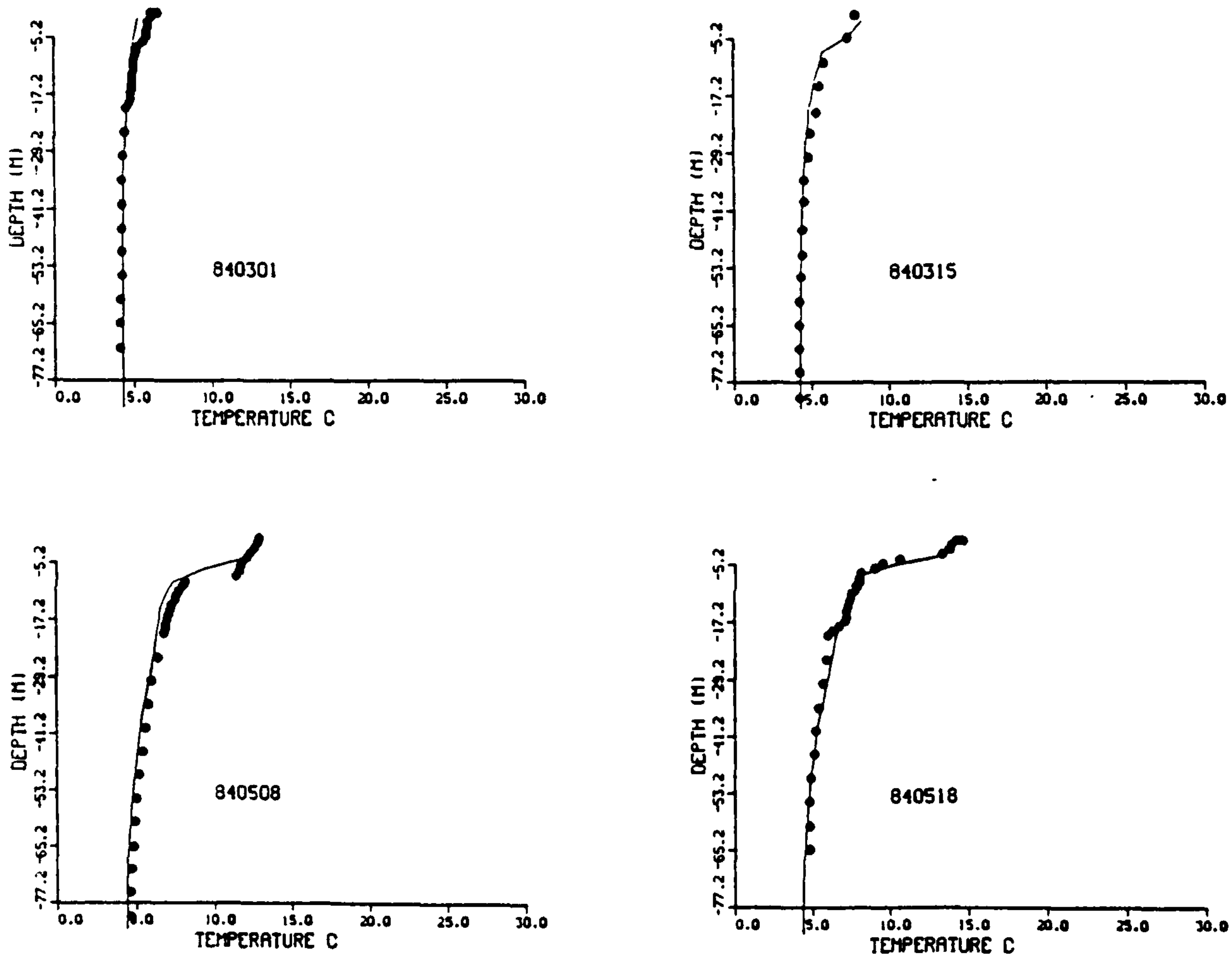


Figure 5. (Sheet 2 of 5)

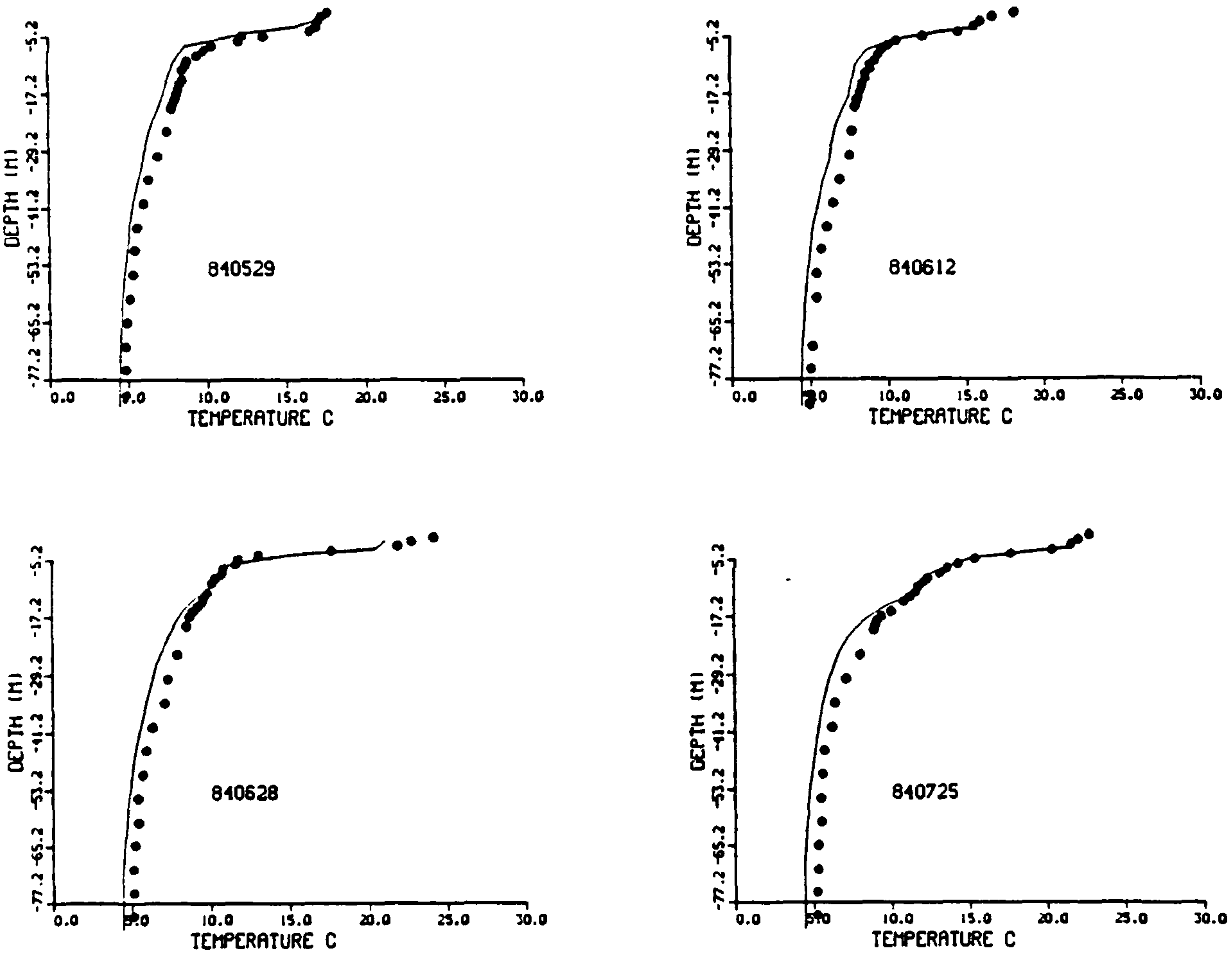


Figure 5. (Sheet 3 of 5)

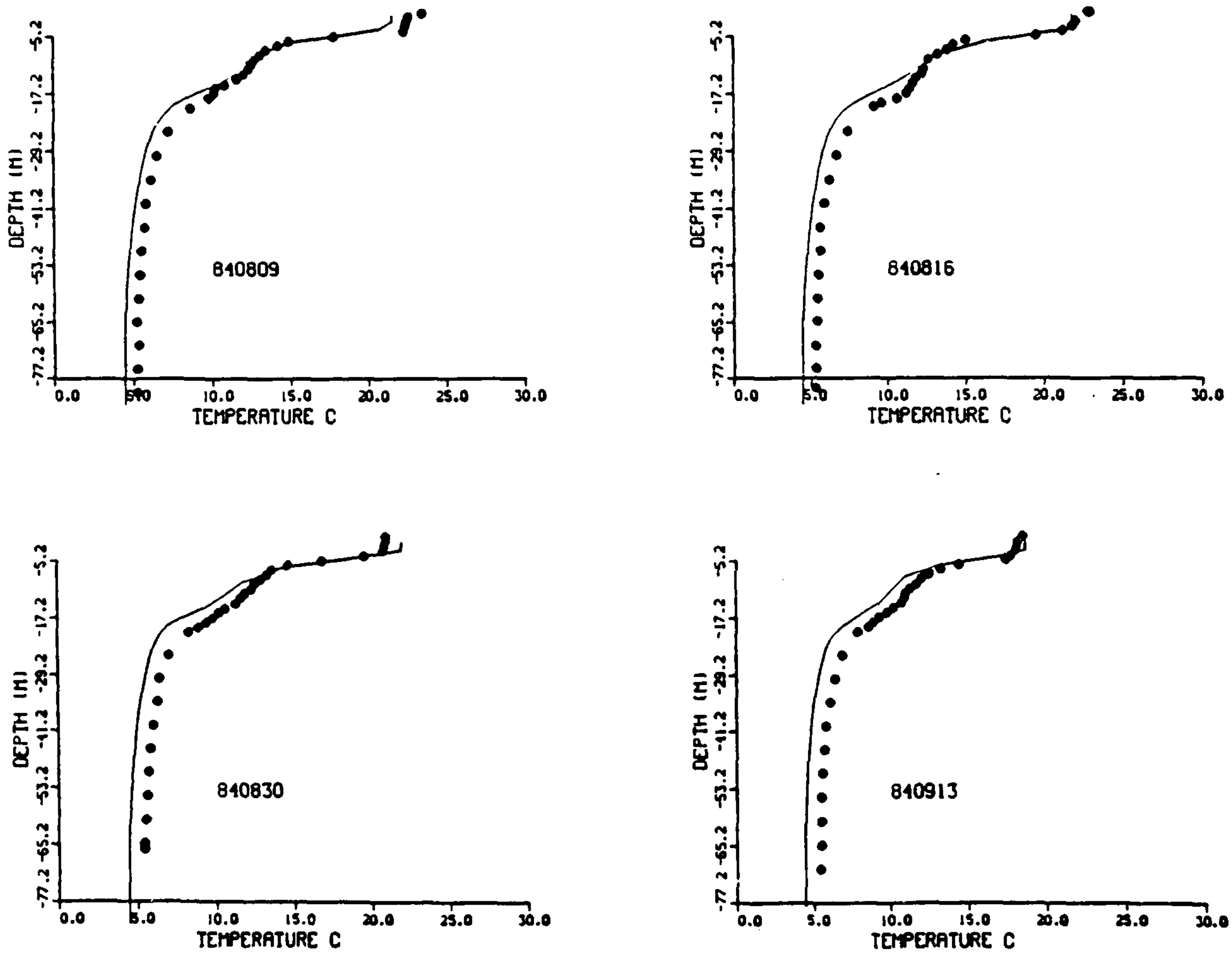


Figure 5. (Sheet 4 of 5)

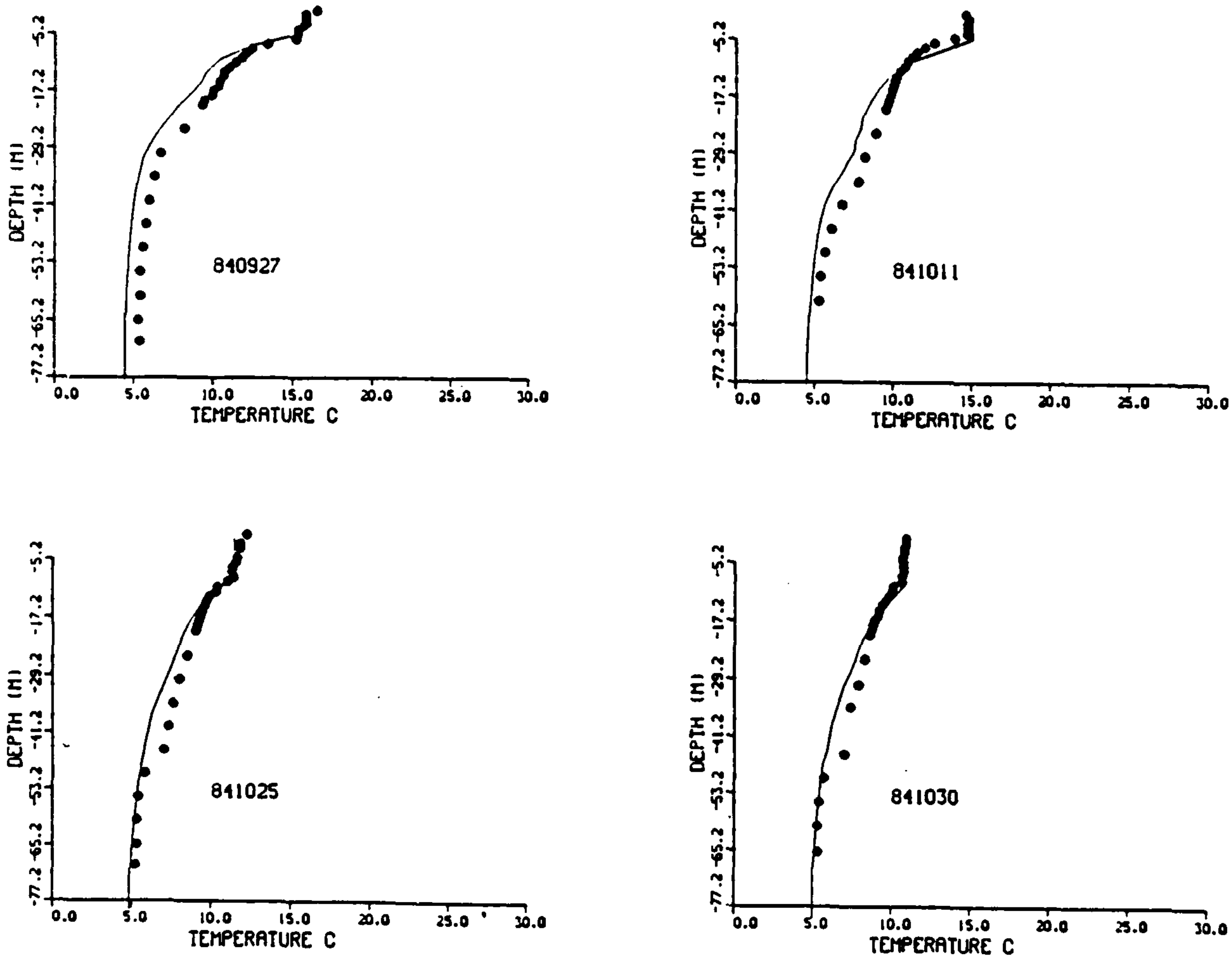


Figure 5. (Sheet 5 of 5)

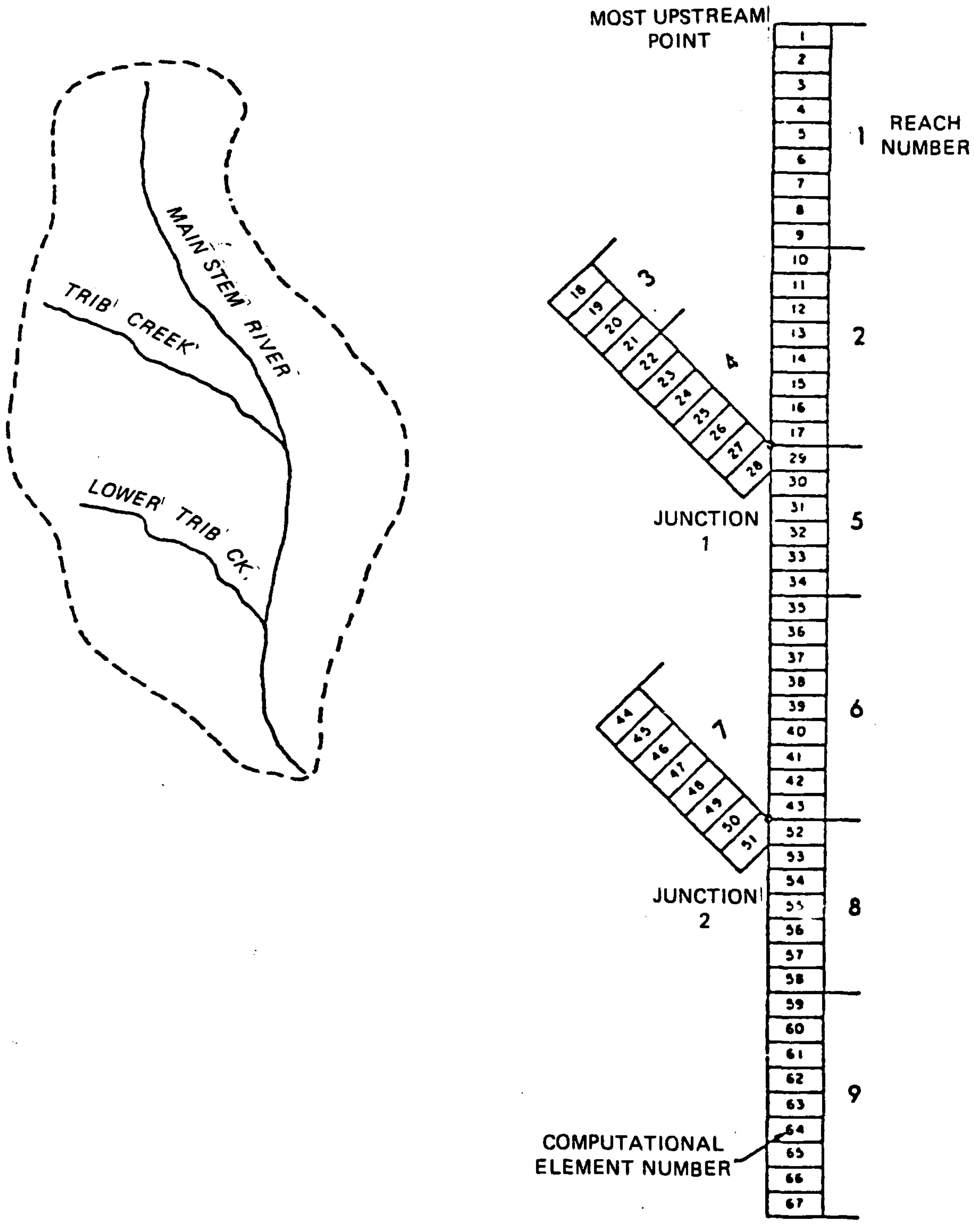
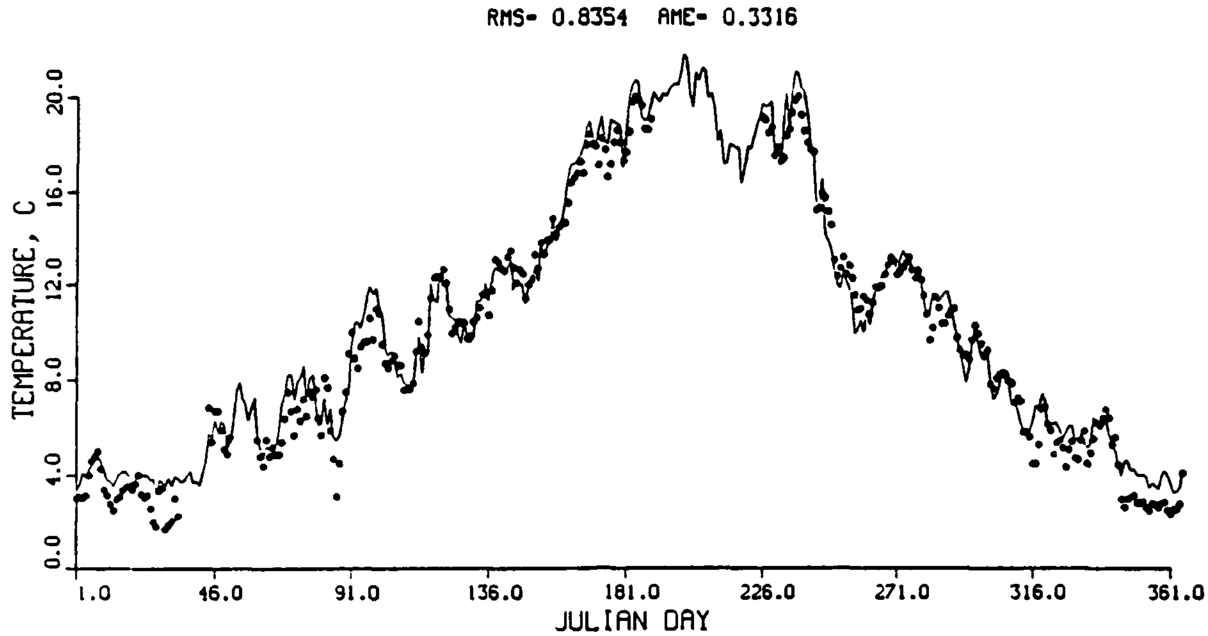
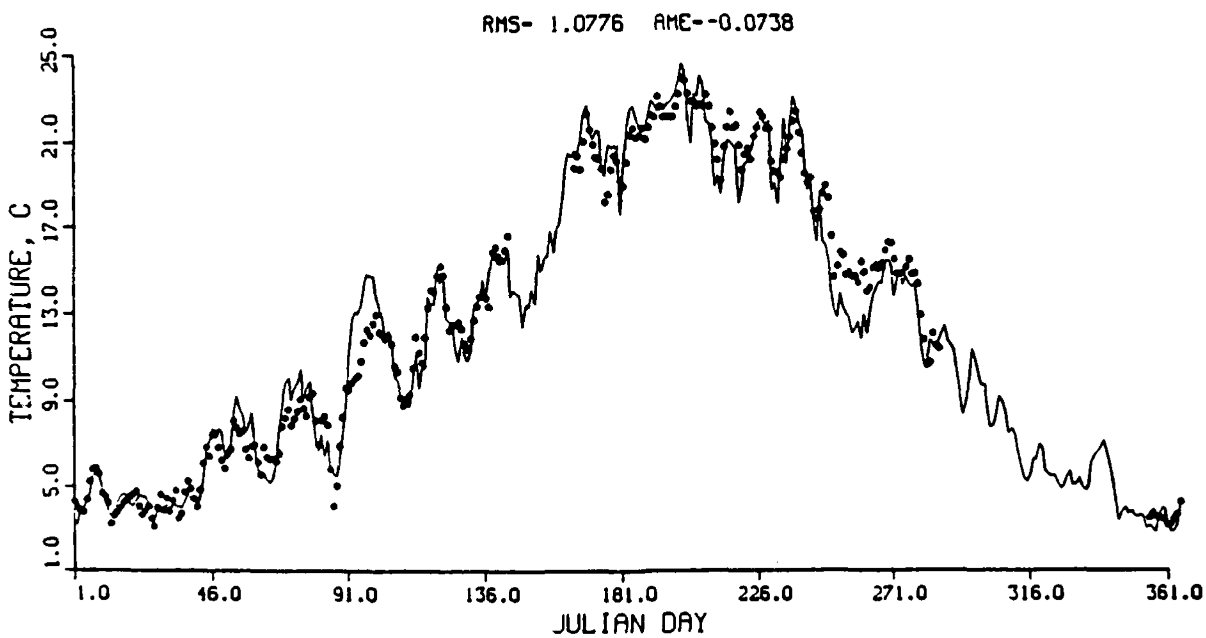


Figure 6. Schematic diagram of a stream system showing computational elements and reaches (after NCASI 1982)



a. At Applegate, RM 27.4



b. Near Wilderville, RM 8.0

Figure 7. Predicted (---) and observed (...) stream temperature data, 1985, Applegate River

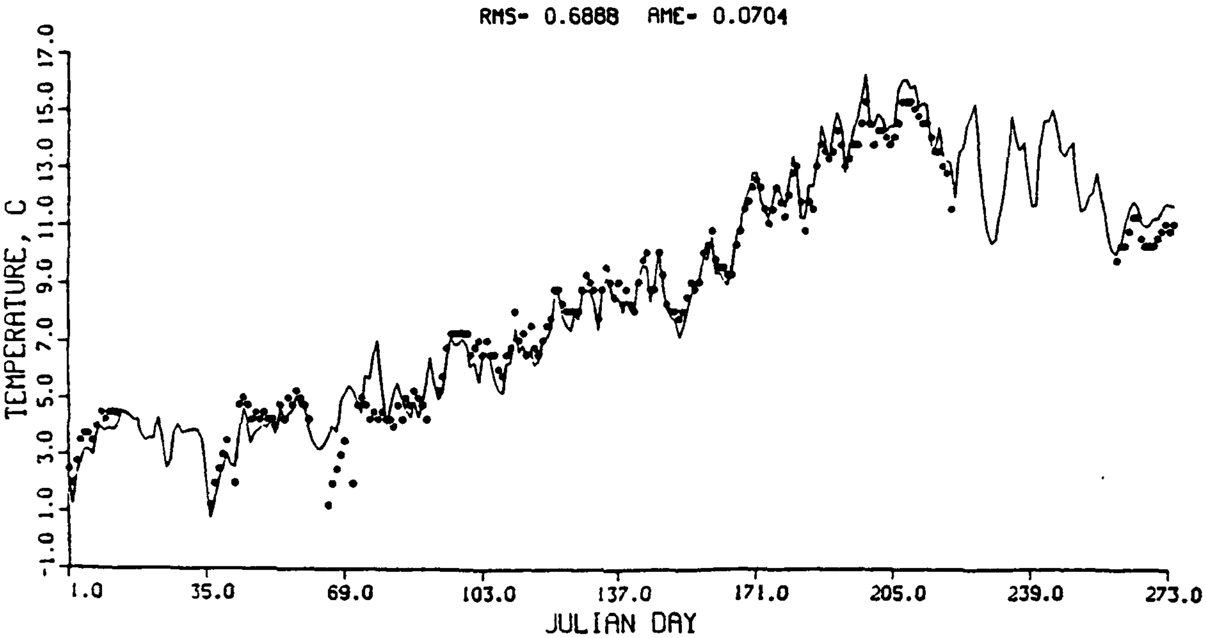
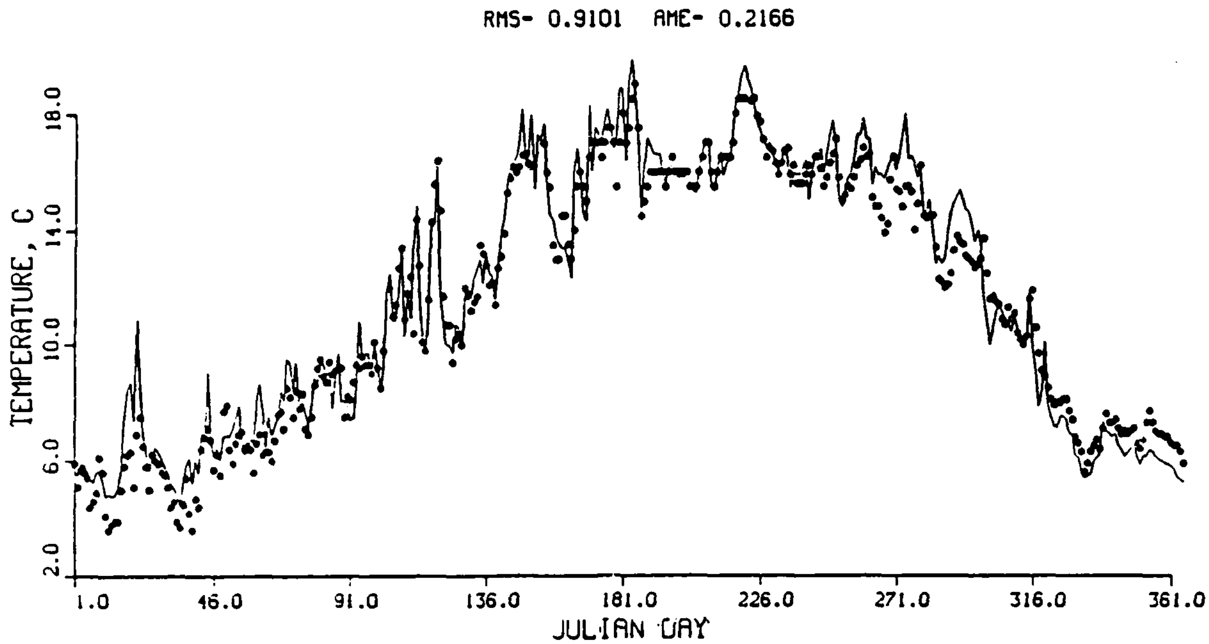
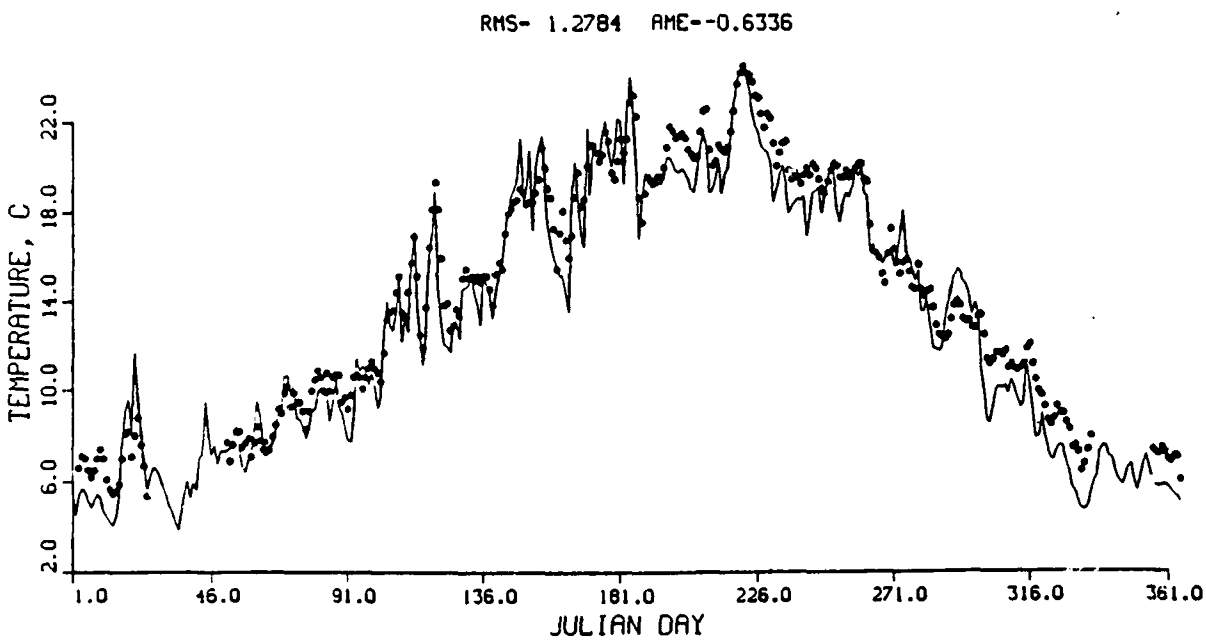


Figure 8. Predicted (---) and observed (...) stream temperature data, 1976, upper Rogue River near McLeod, RM 154.2

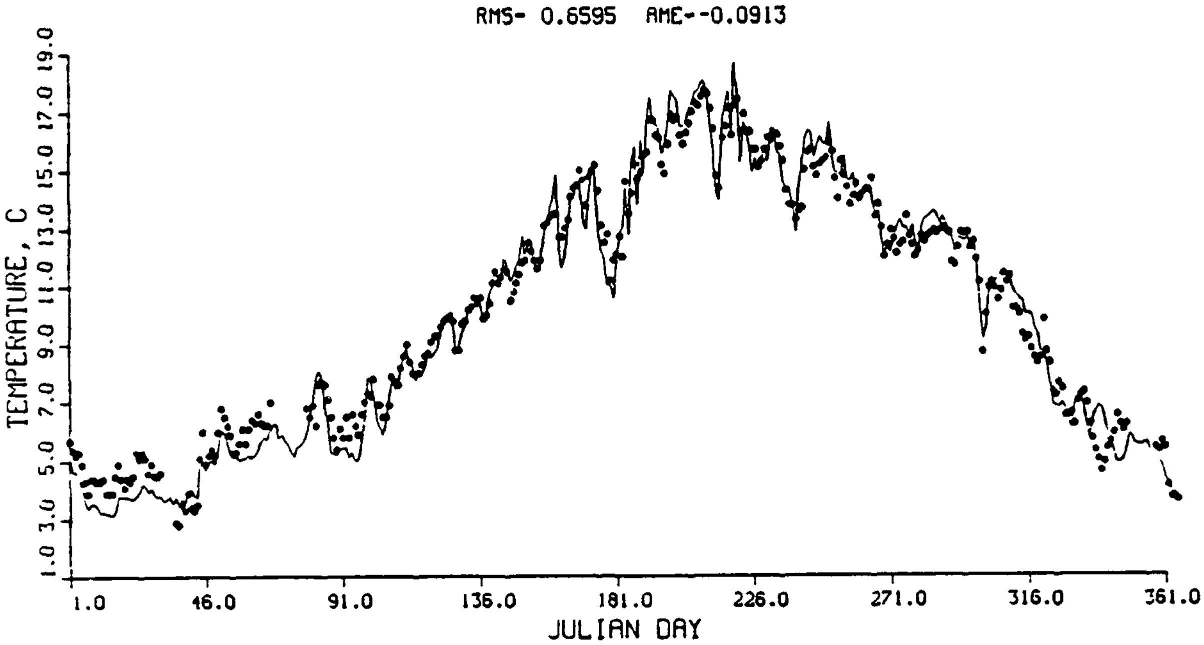


a. At Applegate, RM 27.4

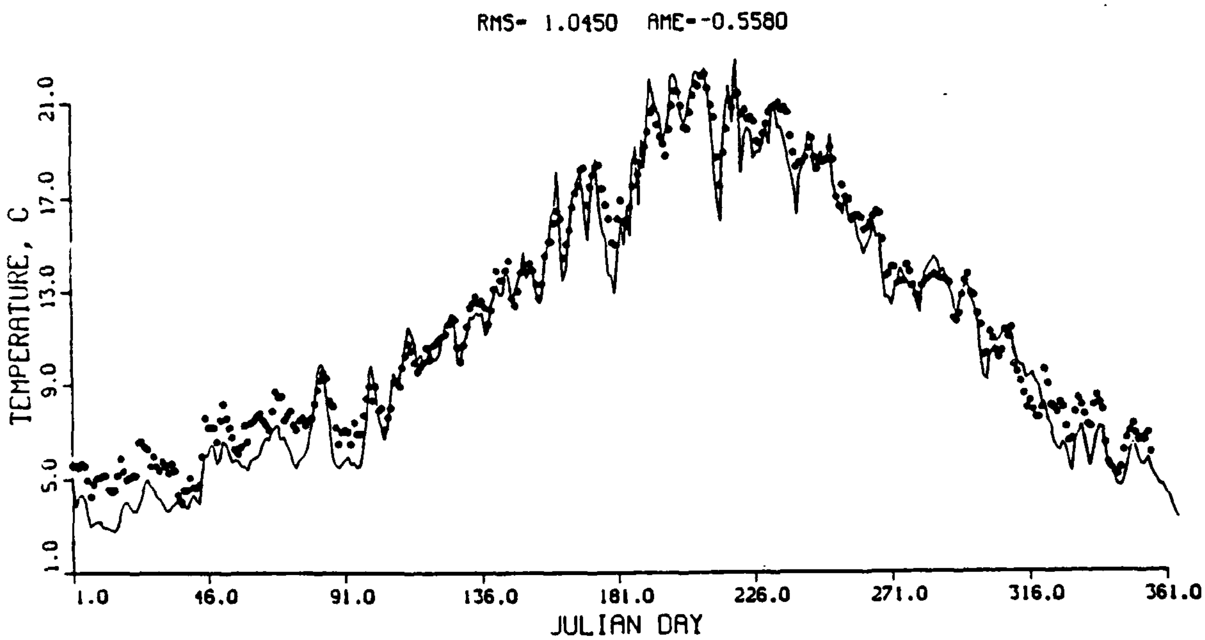


b. Near Wilderville, RM 8.0

Figure 9. Predicted (---) and observed (...) stream temperature data, 1981, Applegate River



a. At Applegate, RM 27.4



b. Near Wilderville, RM 8.0

Figure 10. Predicted (---) and observed (...) stream temperature data, 1982, Applegate River

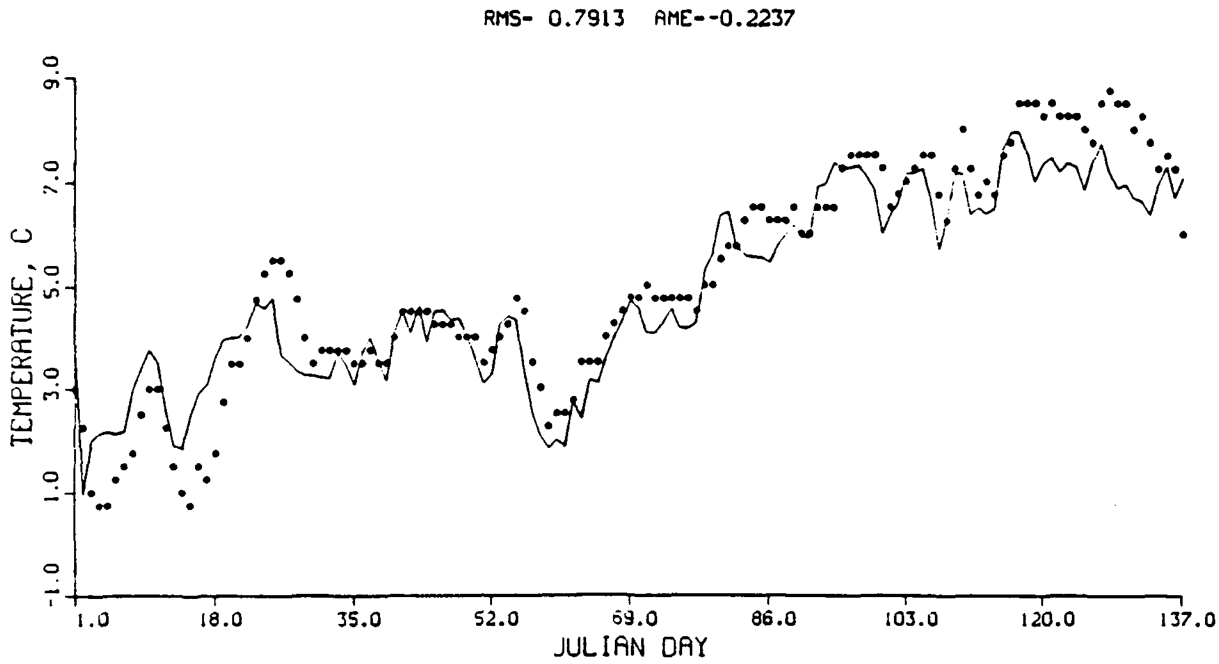
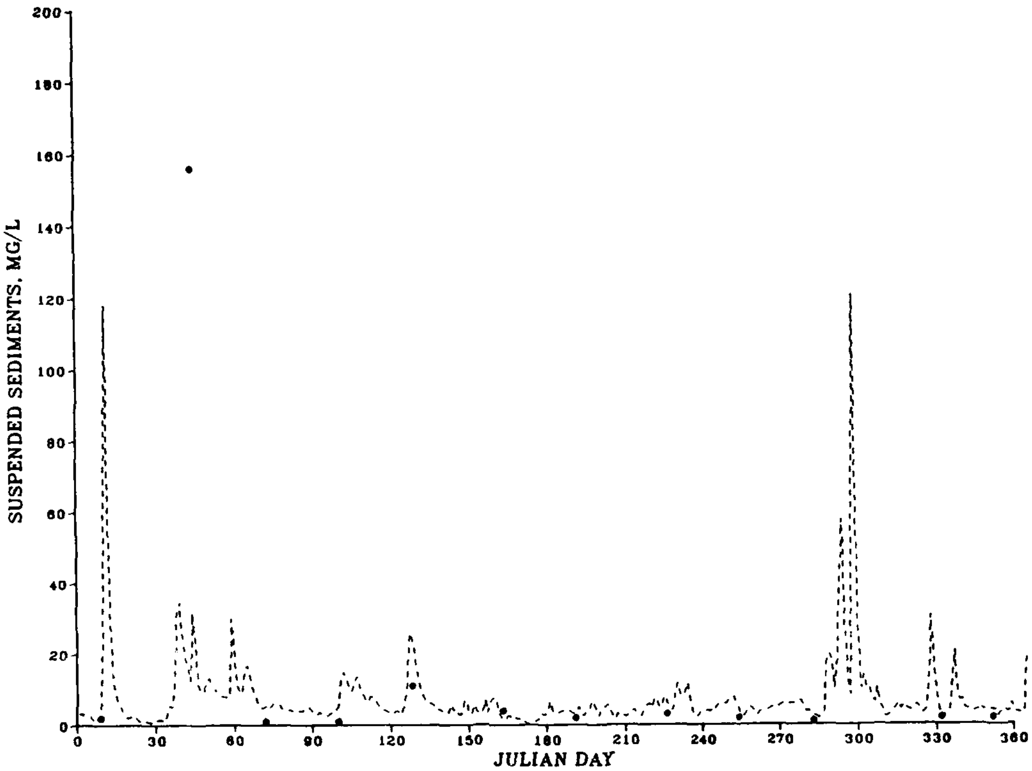
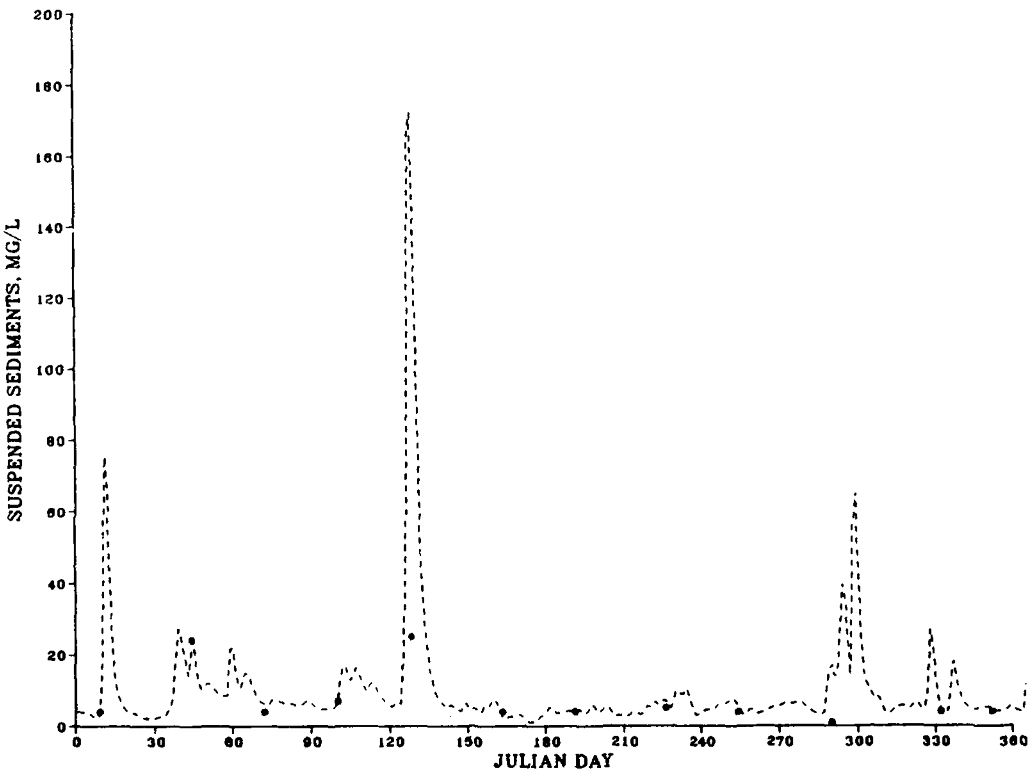


Figure 11. Predicted (---) and observed (...) stream temperature data, 1971, upper Rogue River near McLeod, RM 154.2

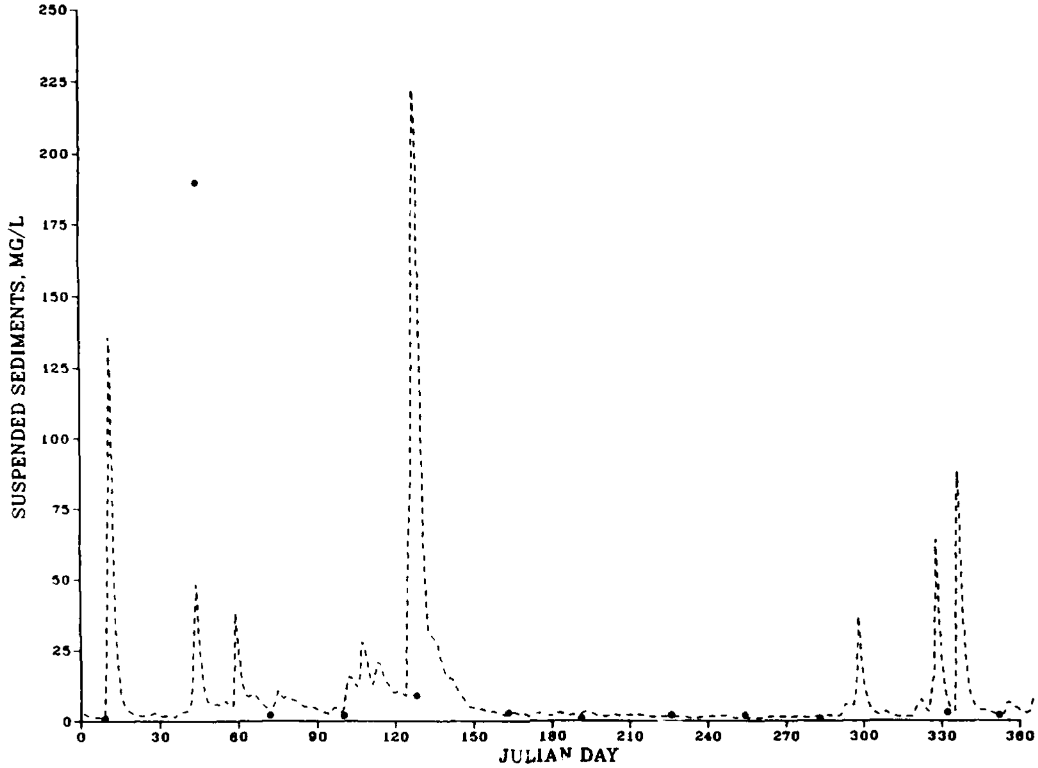


a. "At Dodge Bridge" gaging station

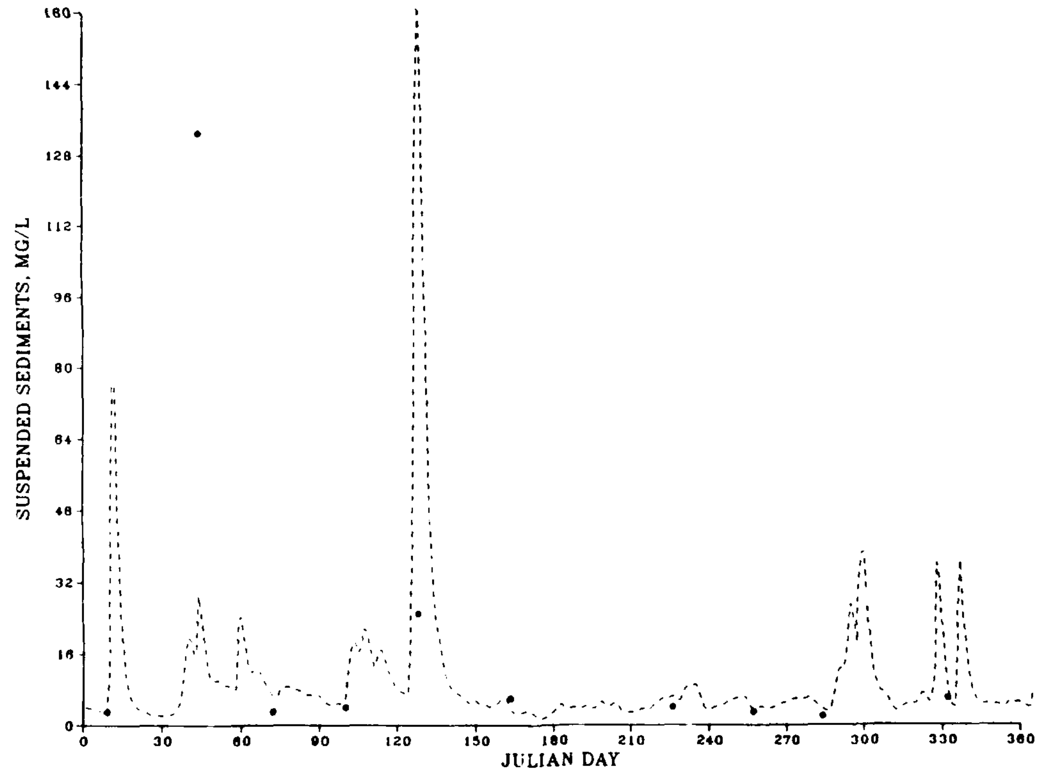


b. "Below Gold Hill" gaging station

Figure 12. Predicted (---) and observed (...) calibration results, 1979, upper Rogue River (Continued)

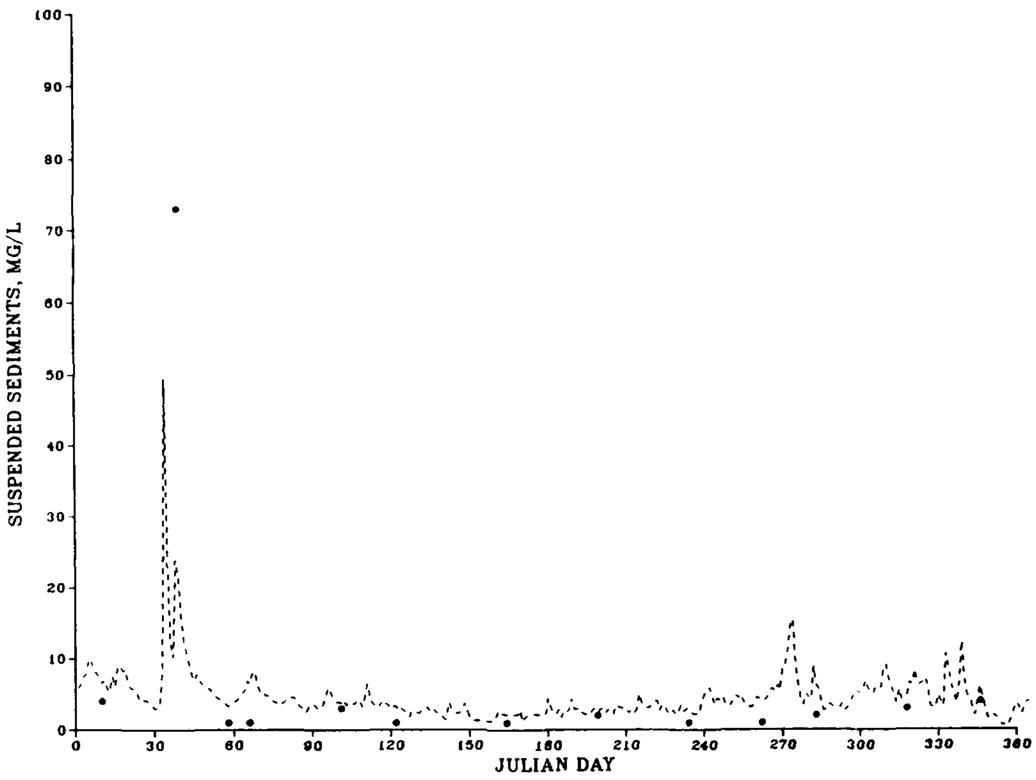


c. "Near Wilderville" gaging station

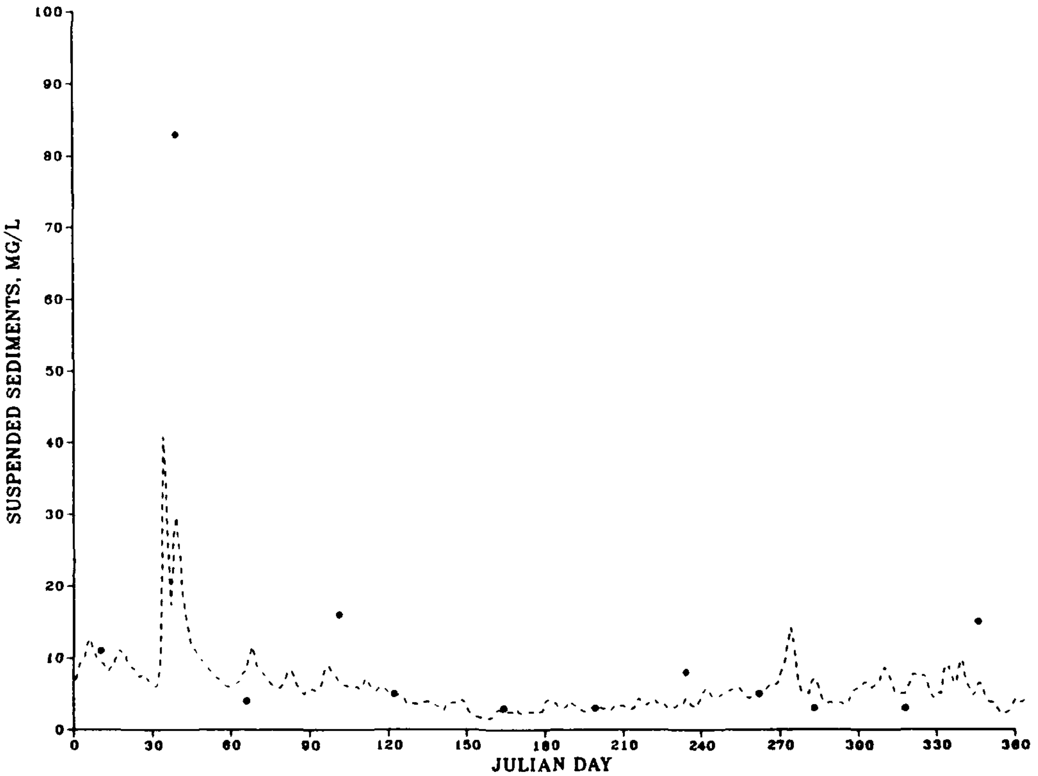


d. "At Merlin" gaging station

Figure 12. (Concluded)

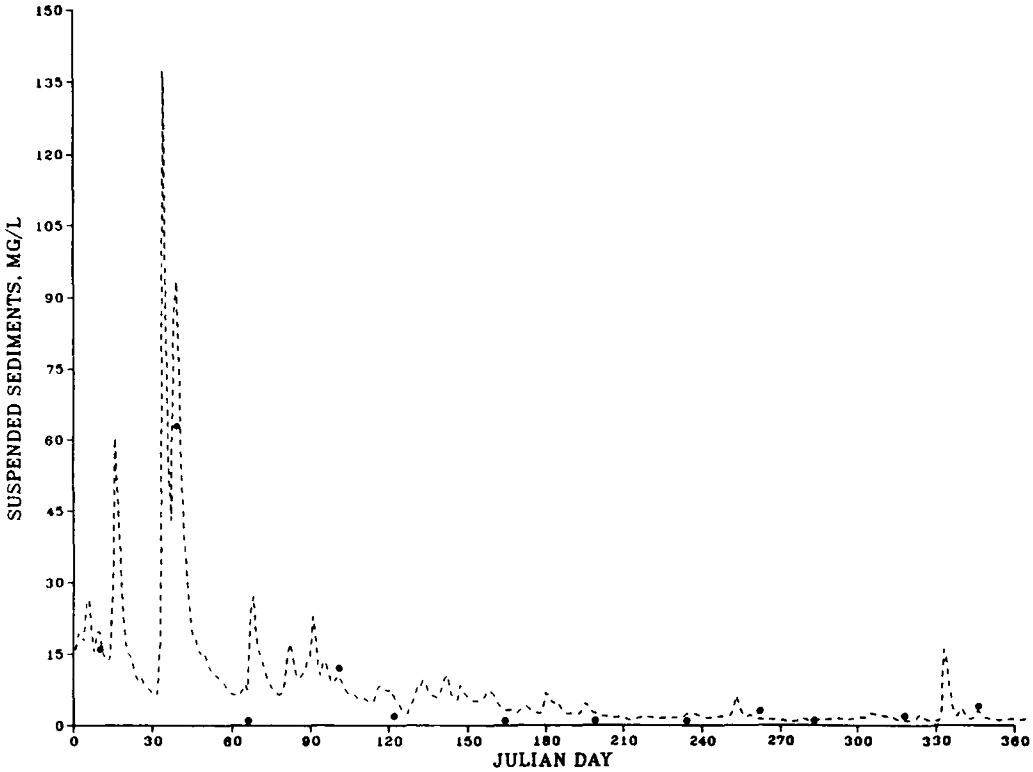


a. "At Dodge Bridge" gaging station

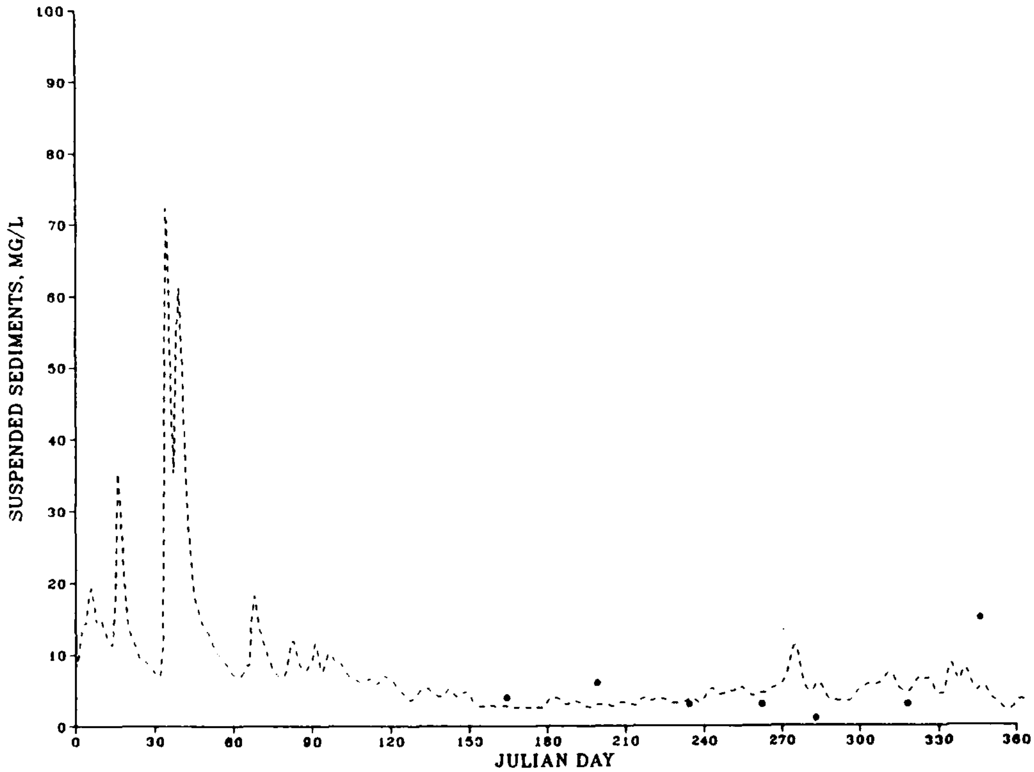


b. "Below Gold Hill" gaging station

Figure 13. Predicted (---) and observed (...) verification results, 1978, upper Rogue River (Continued)



c. "Near Wilderville" gaging station



d. "At Merlin" gaging station

Figure 13. (Concluded)

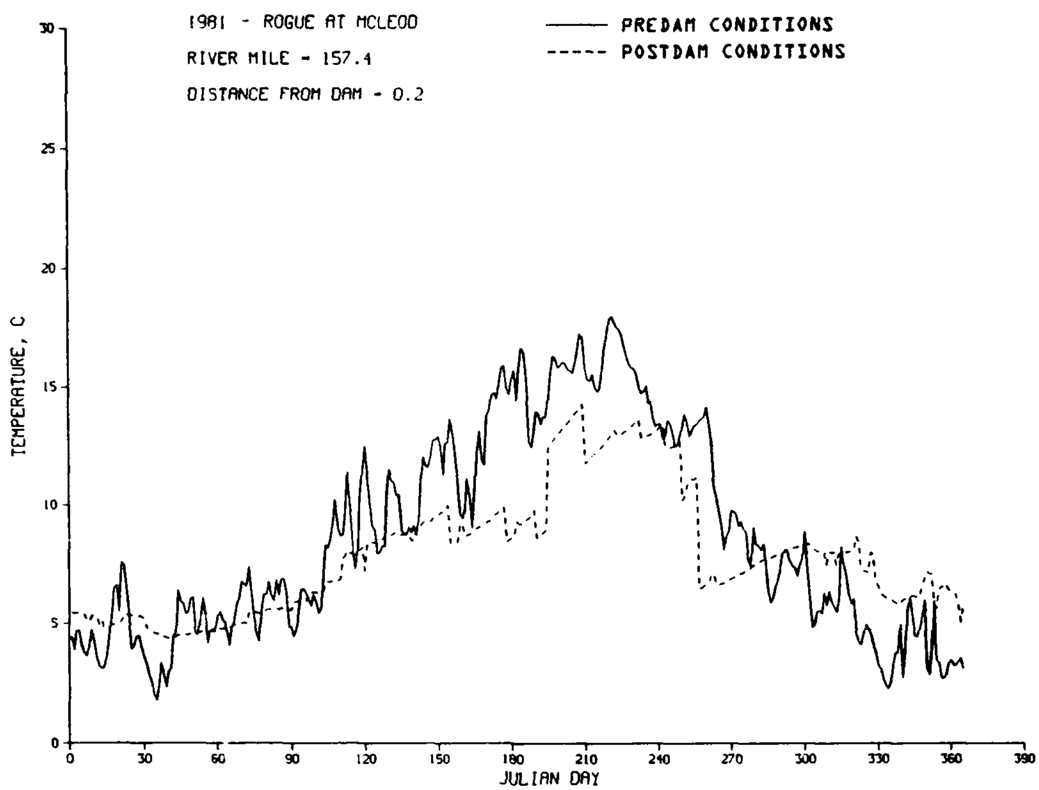


Figure 14. Impact of Lost Creek Dam on Rogue River water temperatures in the immediate tailwater during a dry year

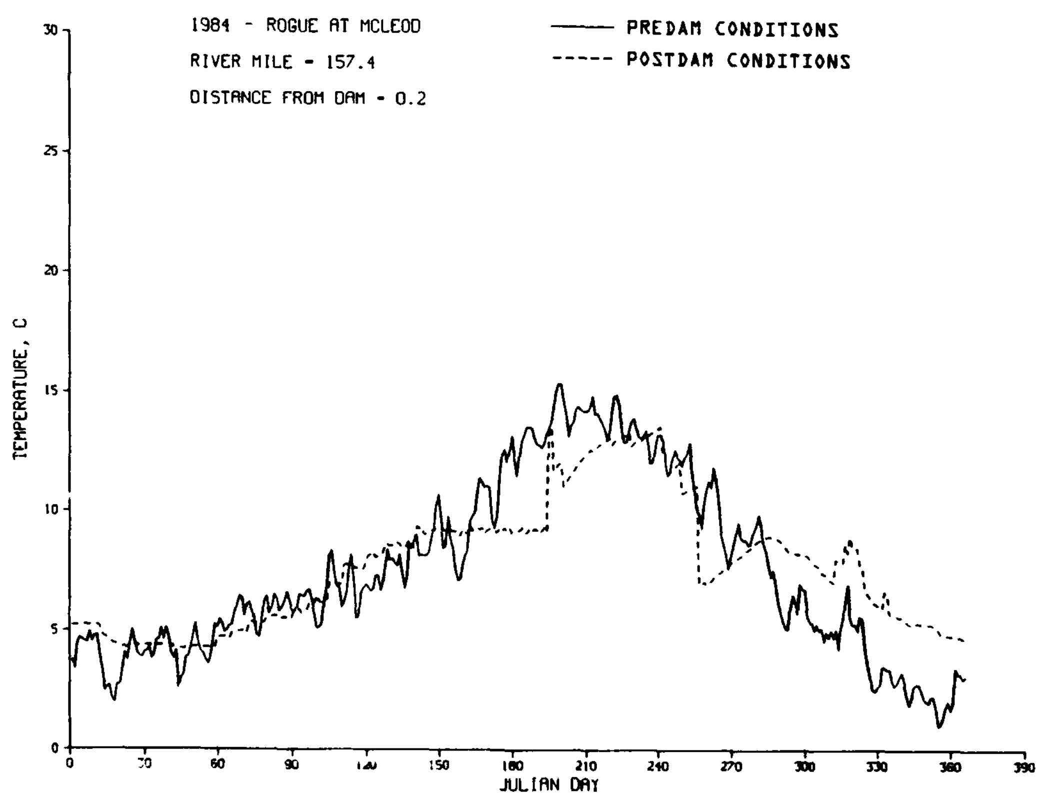


Figure 15. Impact of Lost Creek Dam on Rogue River water temperatures in the immediate tailwater during a wet year

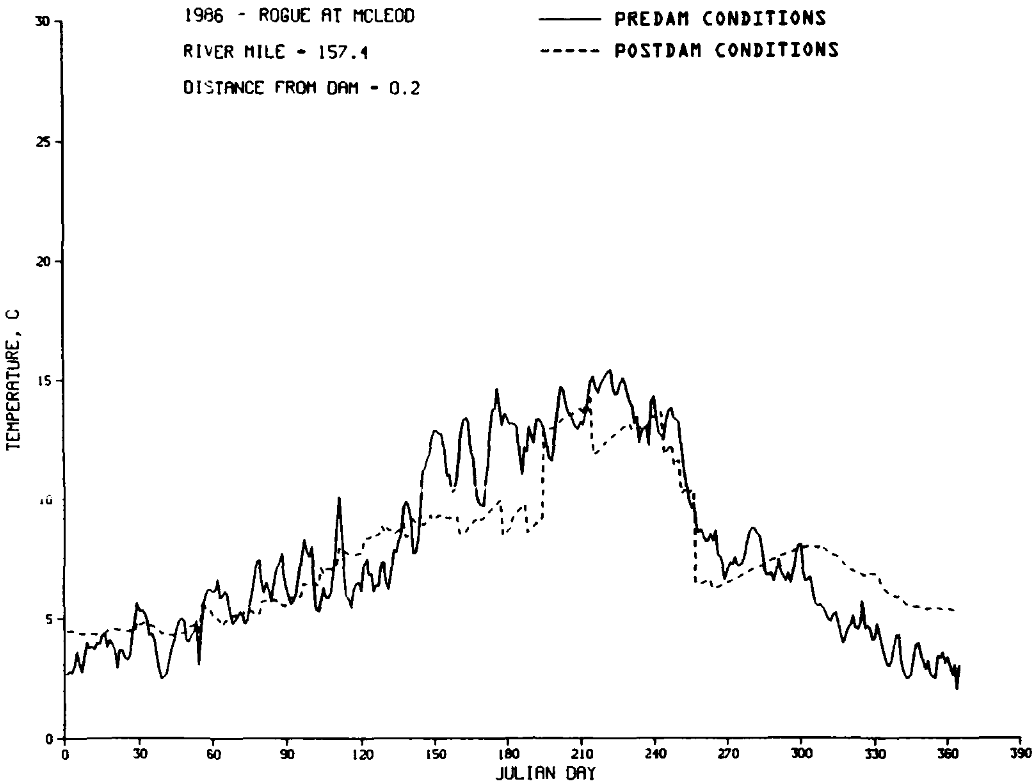


Figure 16. Impact of Lost Creek Dam on Rogue River water temperatures in the immediate tailwater during a normal year

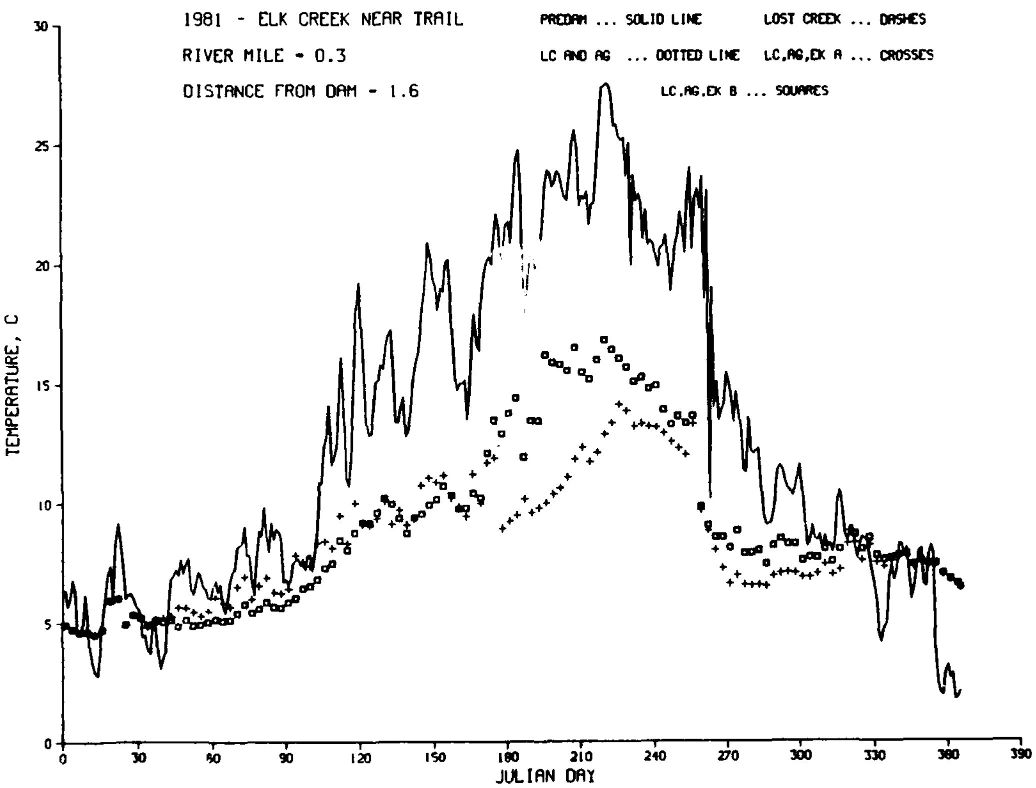


Figure 17. Impact of Elk Creek Dam on Elk Creek water temperatures in the immediate tailwater during a dry year

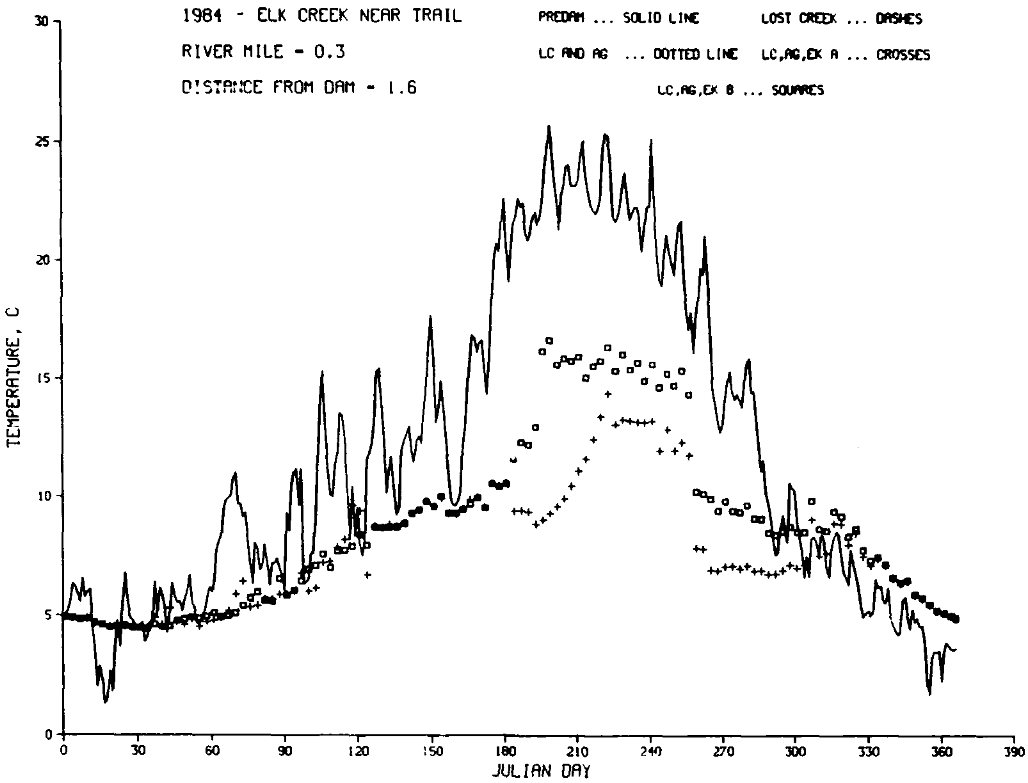


Figure 18. Impact of Elk Creek Dam on Elk Creek water temperatures in the immediate tailwater during a wet year

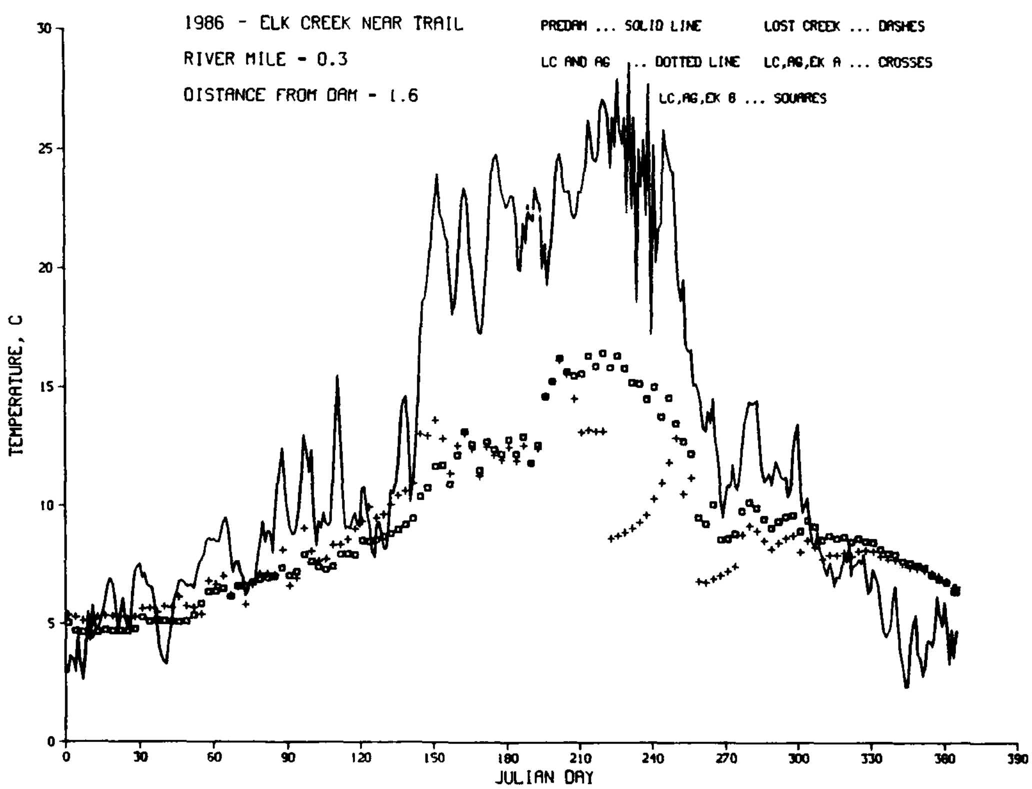


Figure 19. Impact of Elk Creek Dam on Elk Creek water temperatures in the immediate tailwater during a normal year

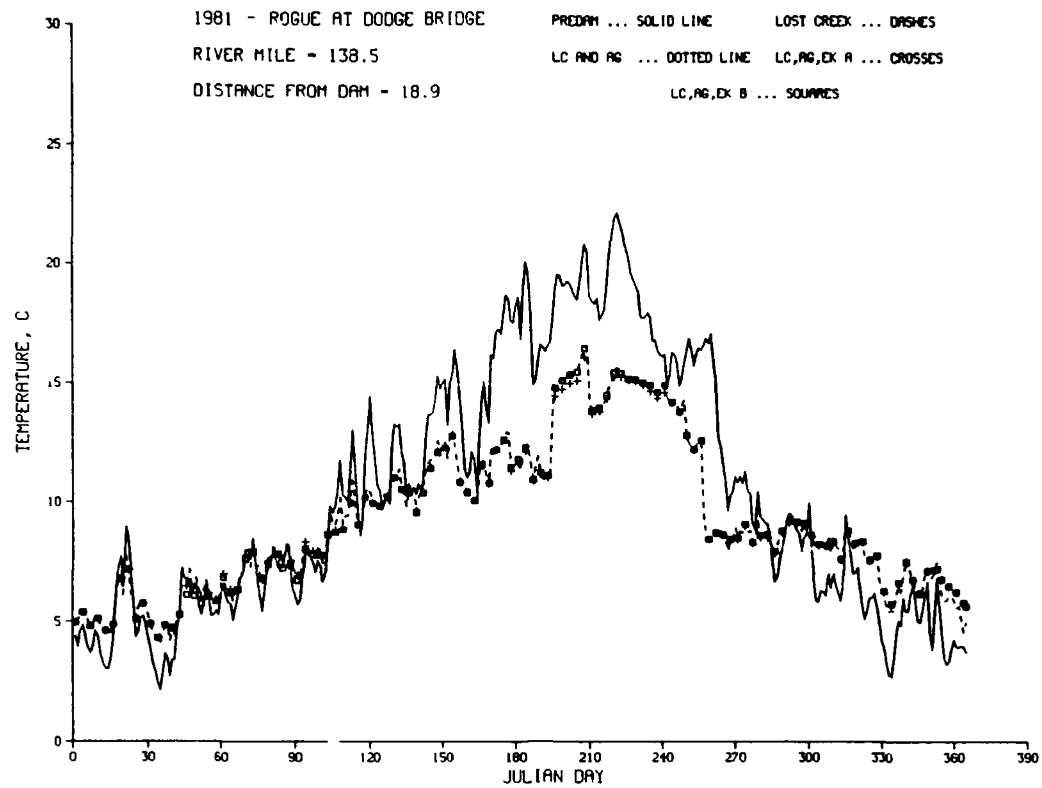


Figure 20. Impact of Elk Creek Dam on Rogue River water temperatures at the "at Dodge Bridge" station during a dry year

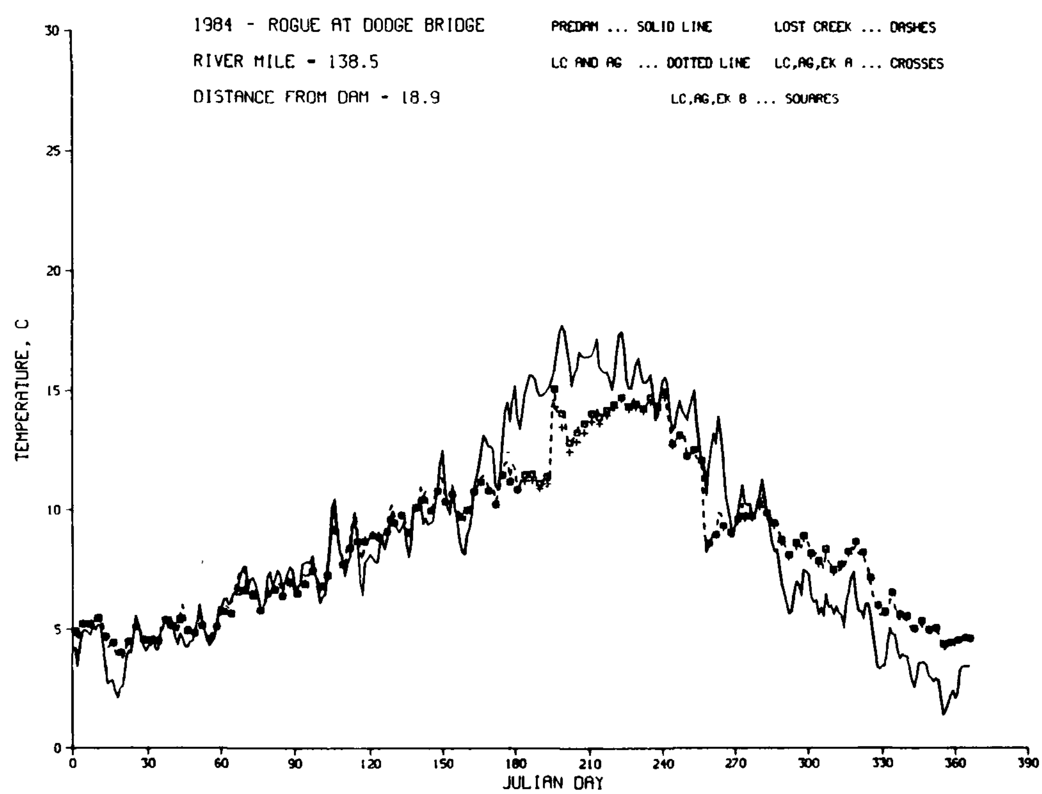


Figure 21. Impact of Elk Creek Dam on Rogue River water temperatures at the "at Dodge Bridge" station during a wet year

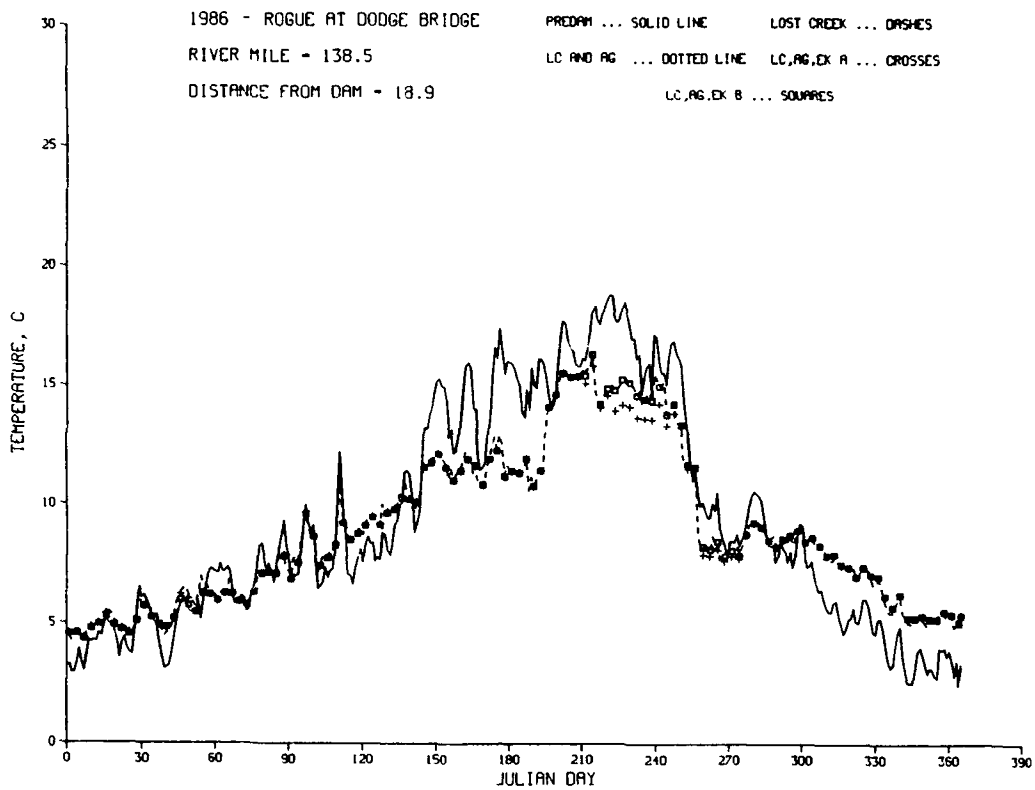


Figure 22. Impact of Elk Creek Dam on Rogue River water temperatures at the "at Dodge Bridge" station during a normal year

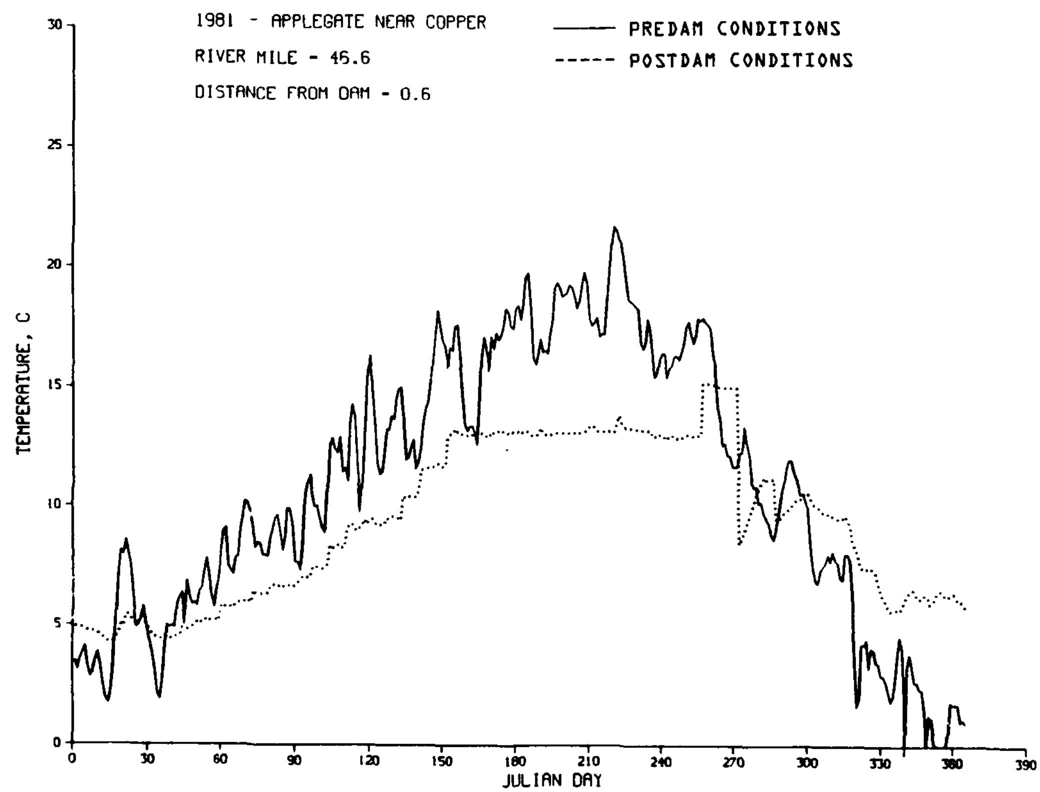


Figure 23. Impact of Applegate Dam on Applegate River water temperatures in the immediate tailwater during a dry year

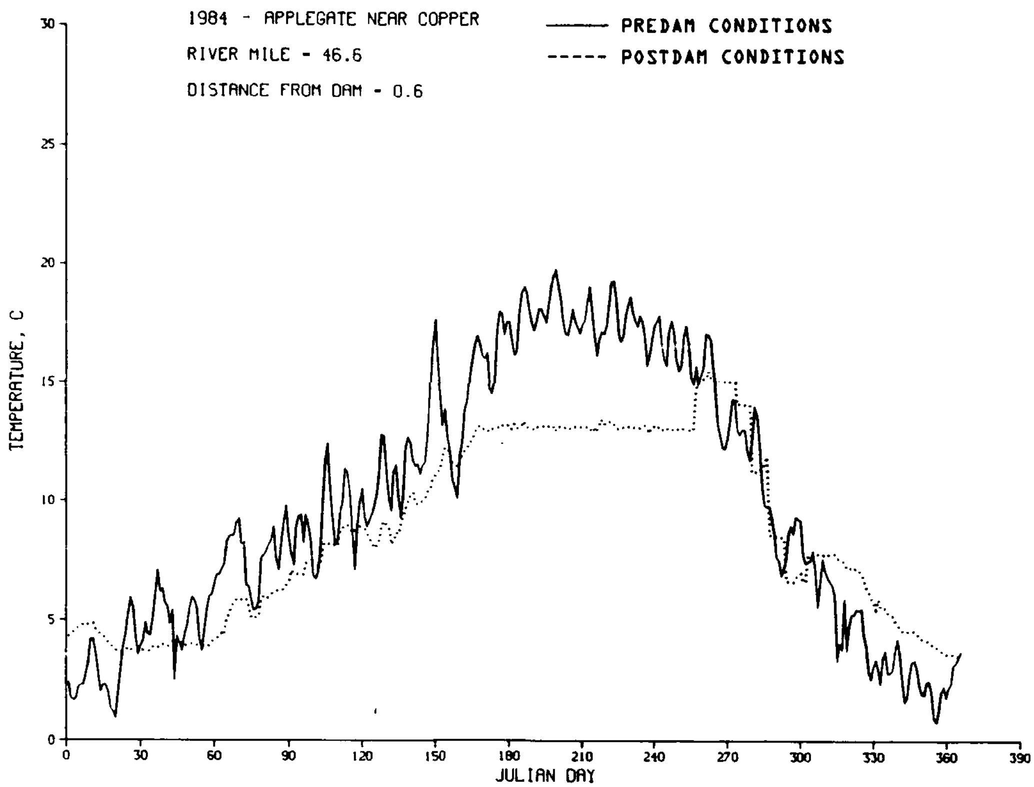


Figure 24. Impact of Applegate Dam on Applegate River water temperatures in the immediate tailwater during a wet year

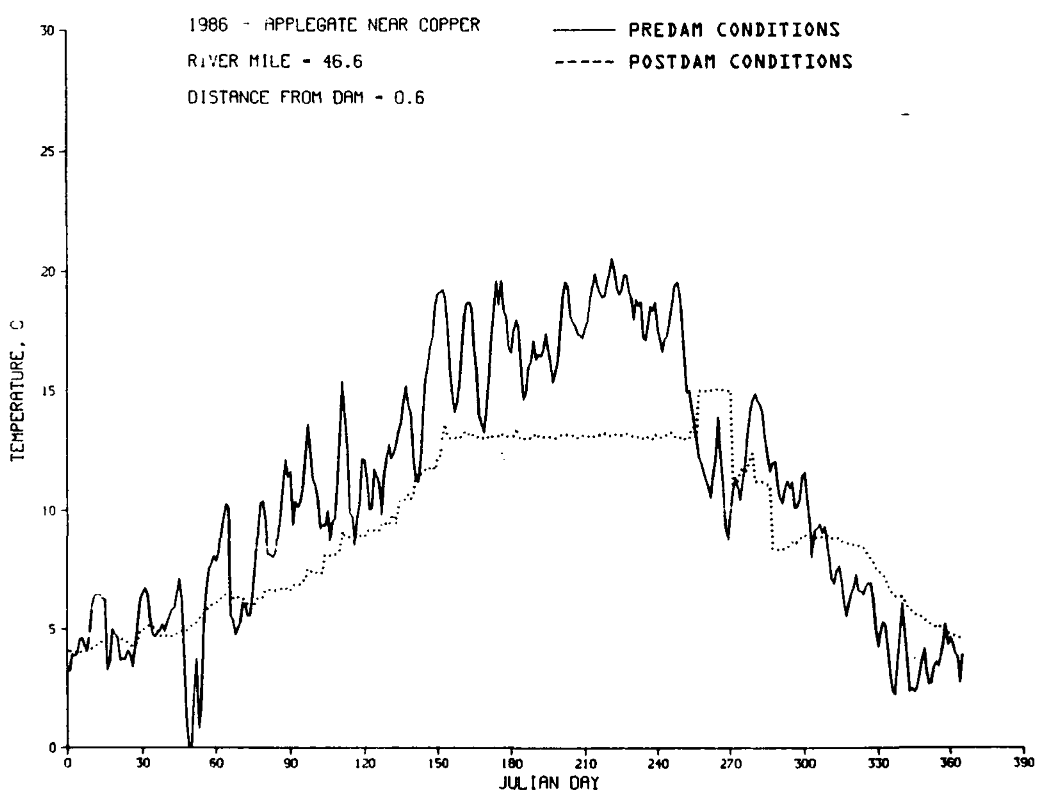


Figure 25. Impact of Applegate Dam on Applegate River water temperatures in the immediate tailwater during a normal year

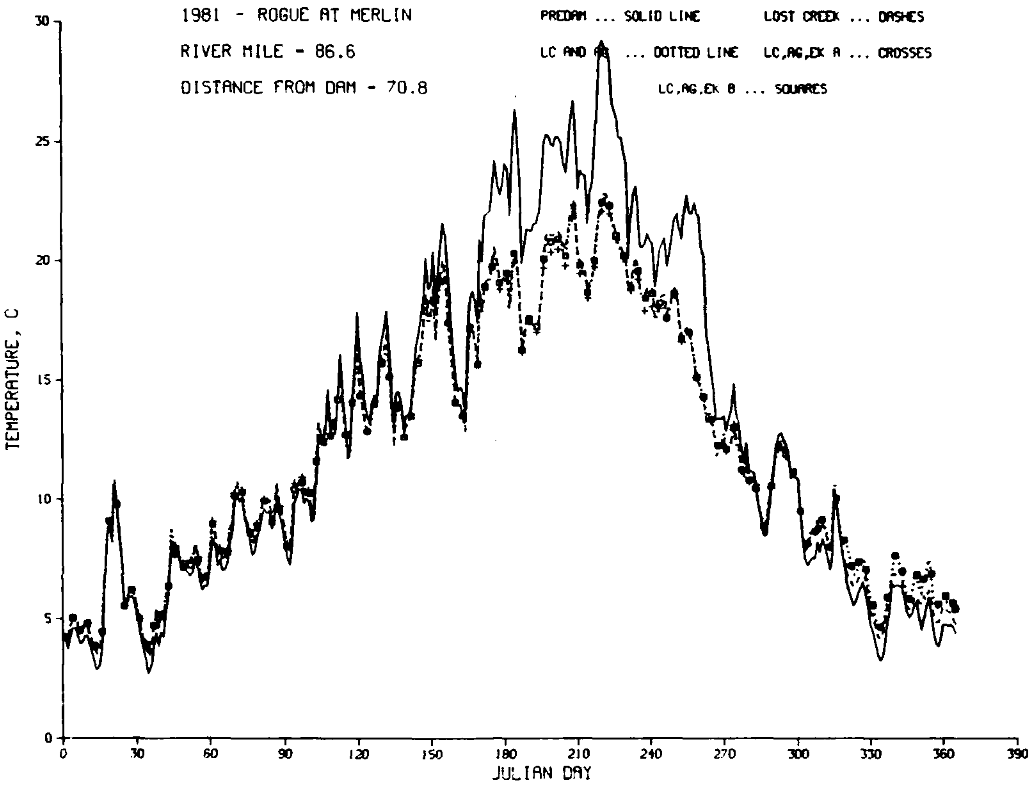


Figure 26. Impact of Applegate Dam on Rogue River water temperatures at the "at Merlin" station during a dry year

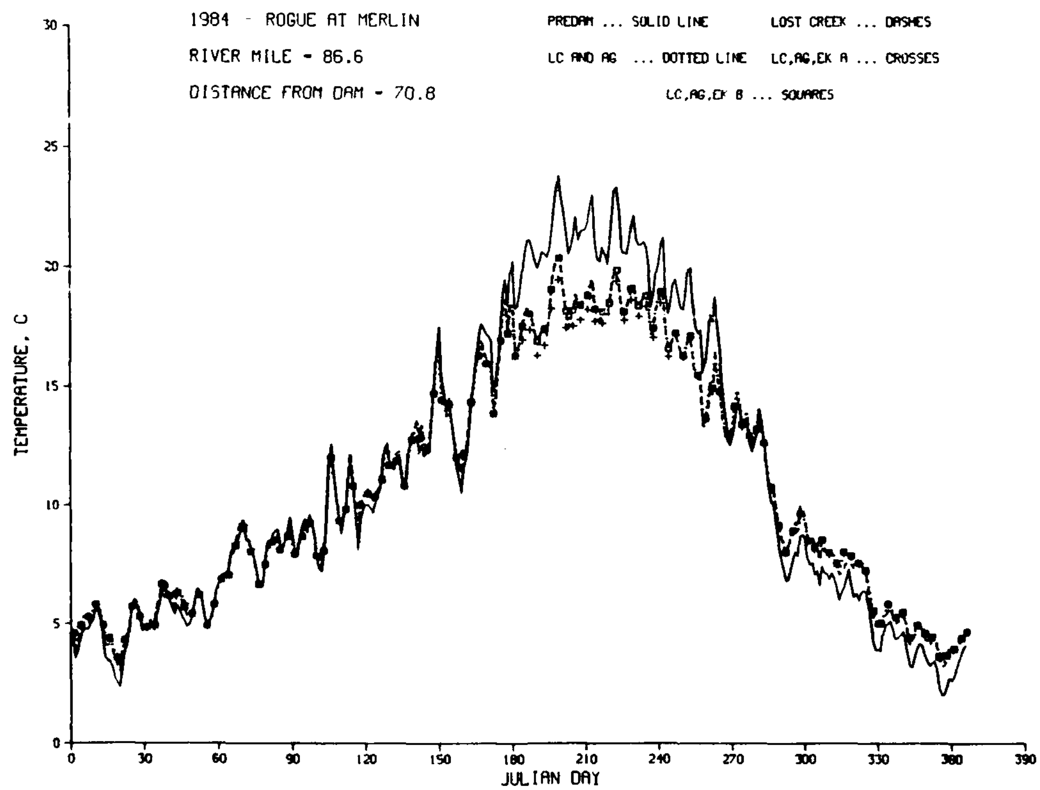


Figure 27. Impact of Applegate Dam on Rogue River water temperatures at the "at Merlin" station during a wet year

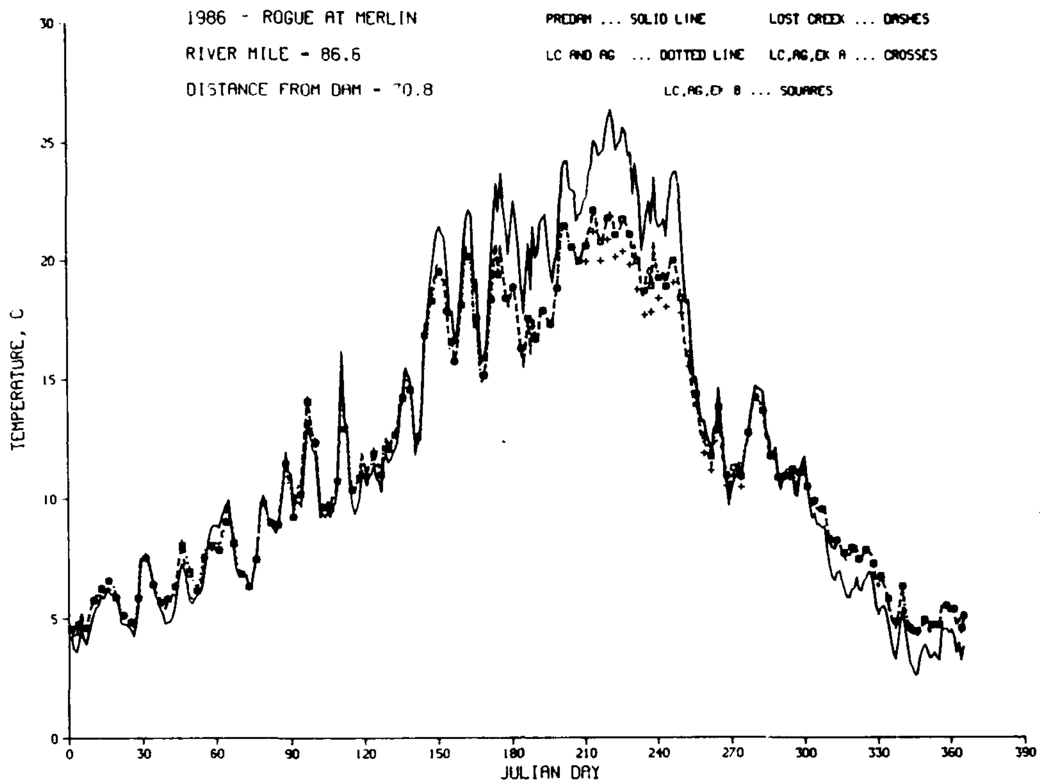


Figure 28. Impact of Applegate Dam on Rogue River water temperatures at the "at Merlin" station during a normal year

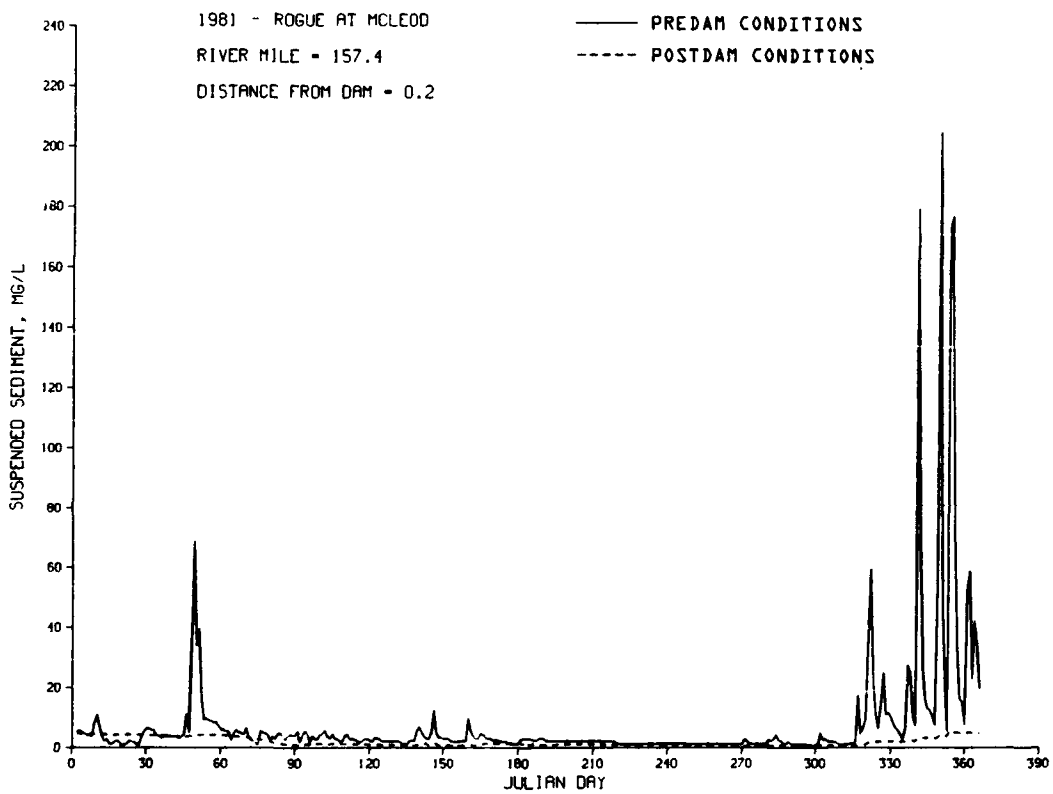


Figure 29. Impact of Lost Creek Dam on Rogue River suspended sediment concentration in the immediate tailwater during a dry year

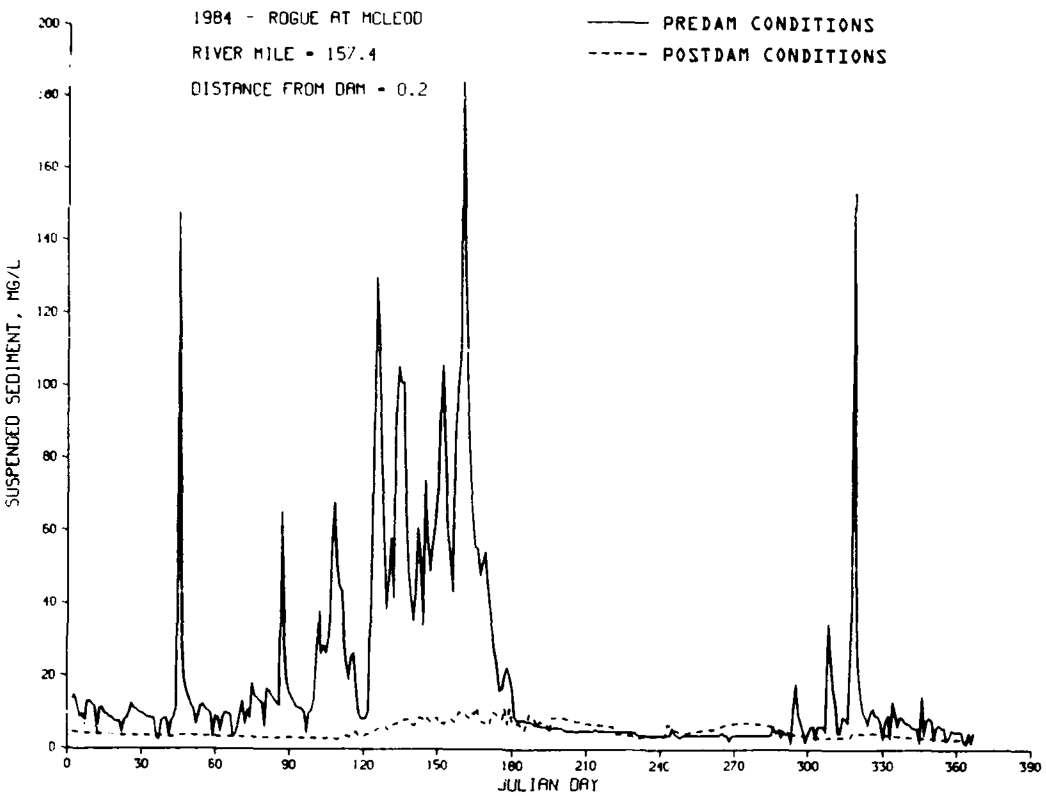


Figure 30. Impact of Lost Creek Dam on Rogue River suspended sediment concentration in the immediate tailwater during a wet year

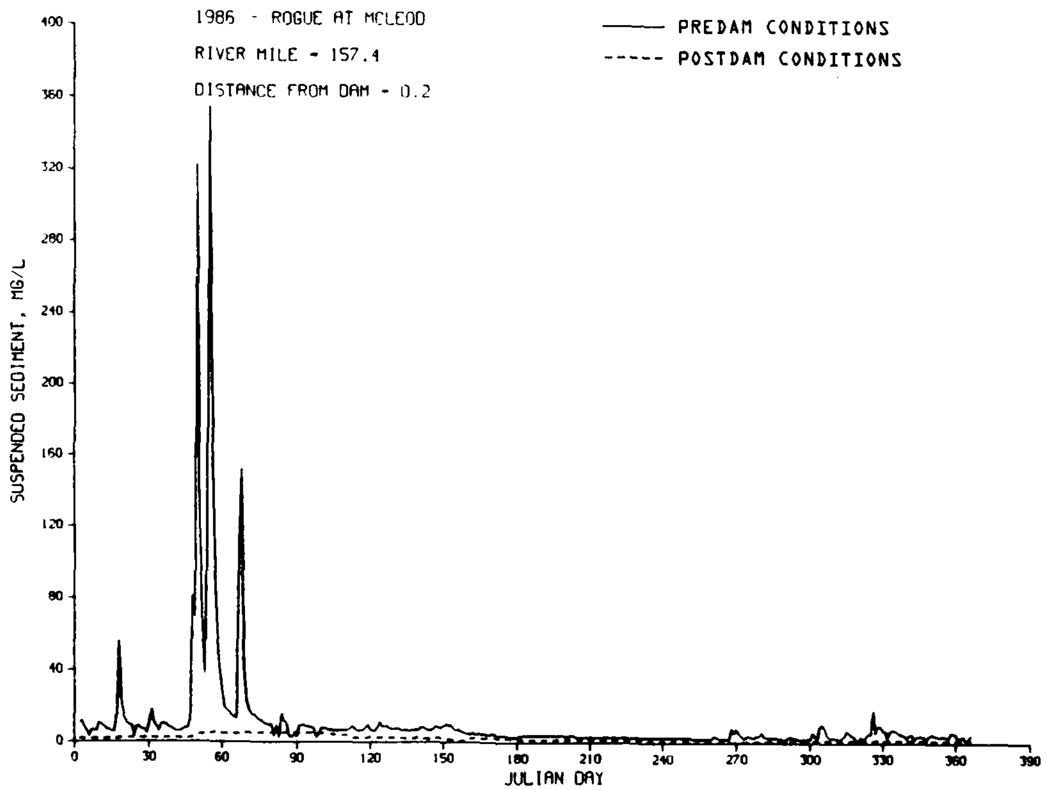


Figure 31. Impact of Lost Creek Dam on Rogue River suspended sediment concentration in the immediate tailwater during a normal year

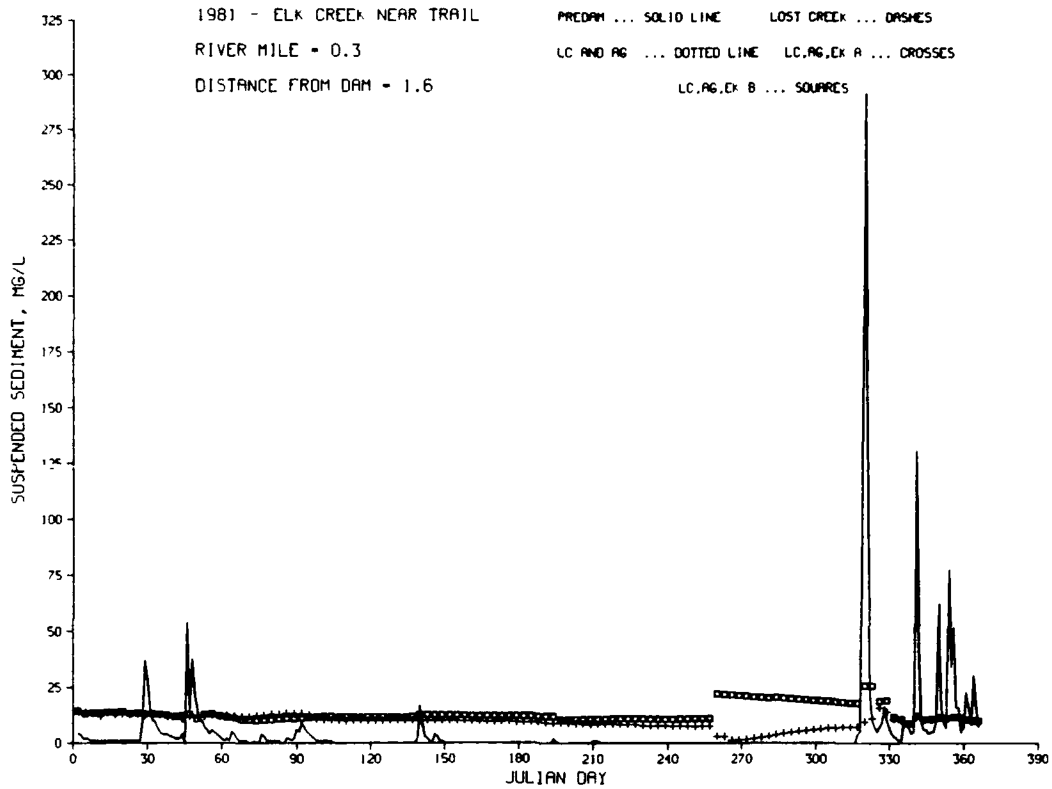


Figure 32. Impact of Elk Creek Dam on Elk Creek suspended sediment concentration in the immediate tailwater during a dry year

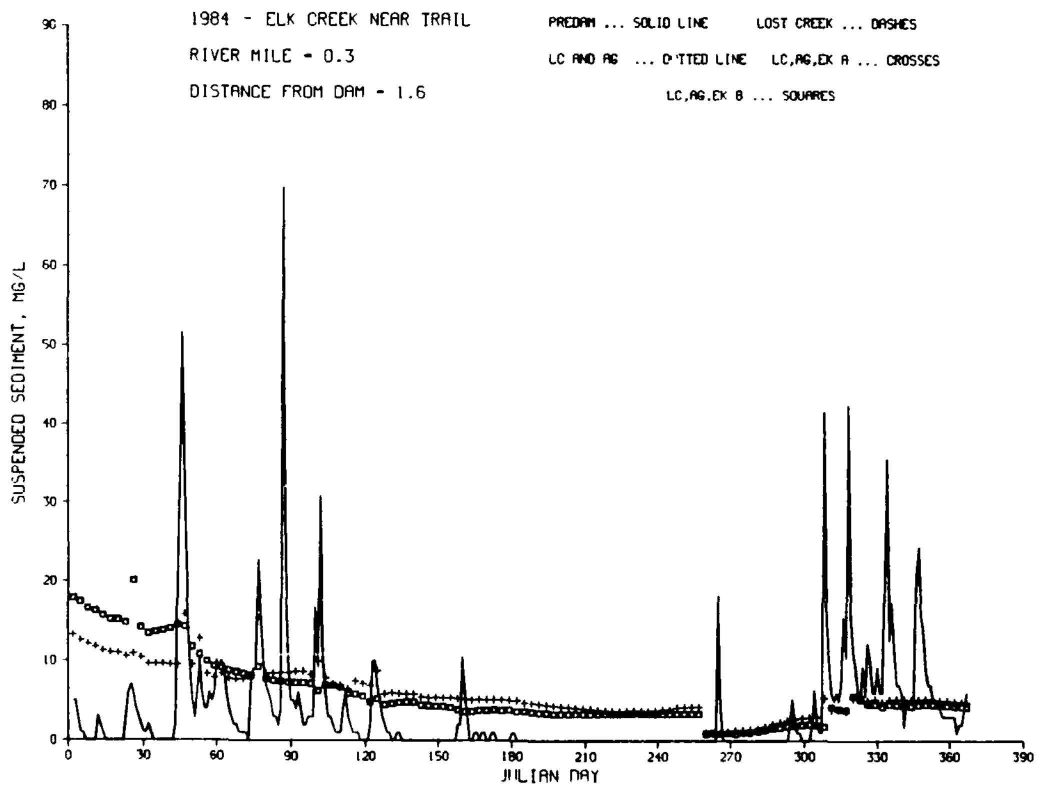


Figure 33. Impact of Elk Creek Dam on Elk Creek suspended sediment concentration in the immediate tailwater during a wet year

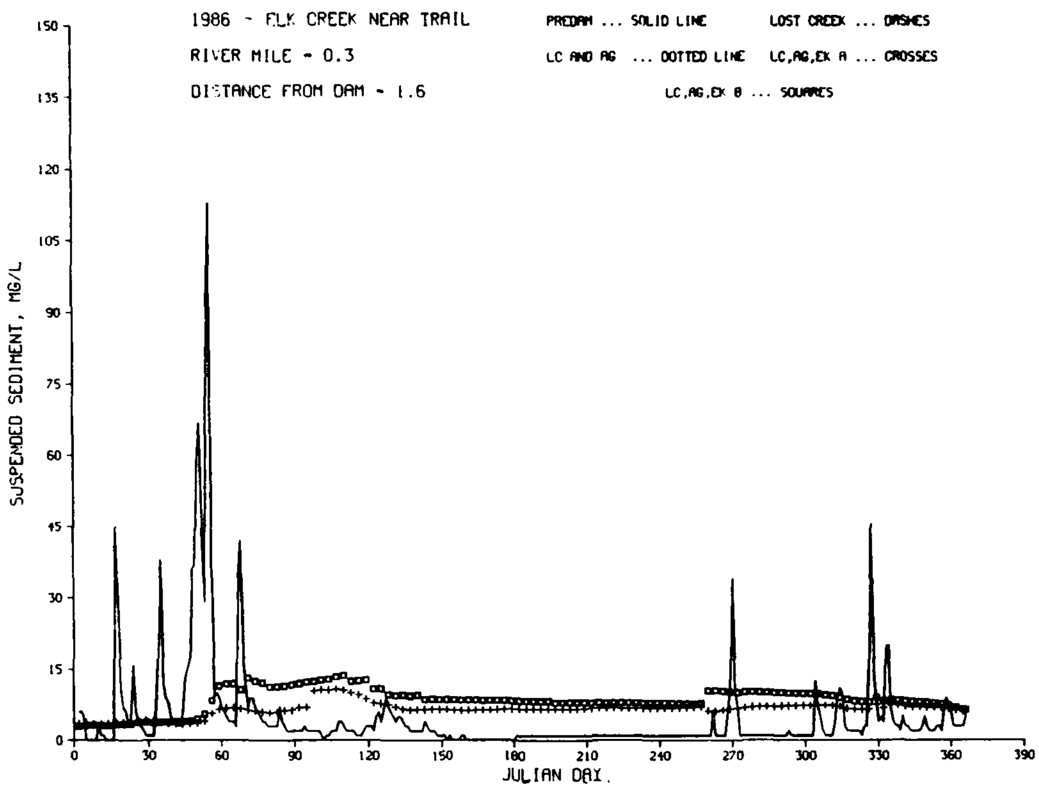


Figure 34. Impact of Elk Creek Dam on Elk Creek suspended sediment concentration in the immediate tailwater during a normal year

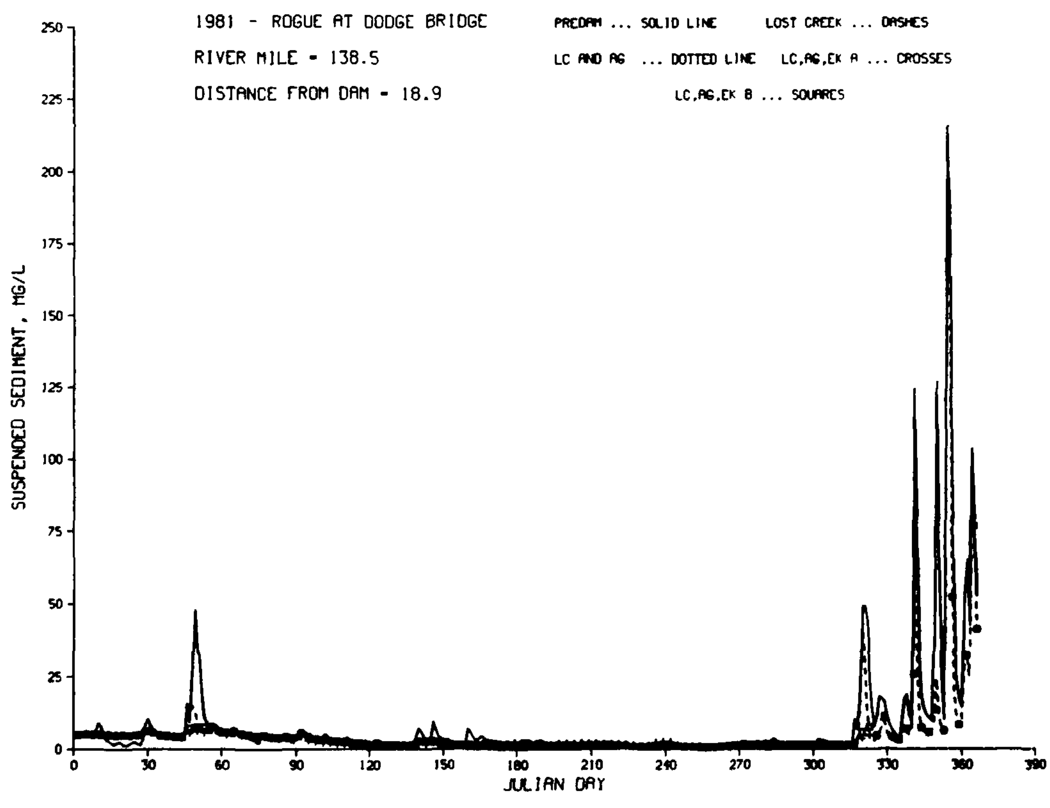


Figure 35. Impact of Elk Creek Dam on Rogue River suspended sediment concentration at the "at Dodge Bridge" station during a dry year

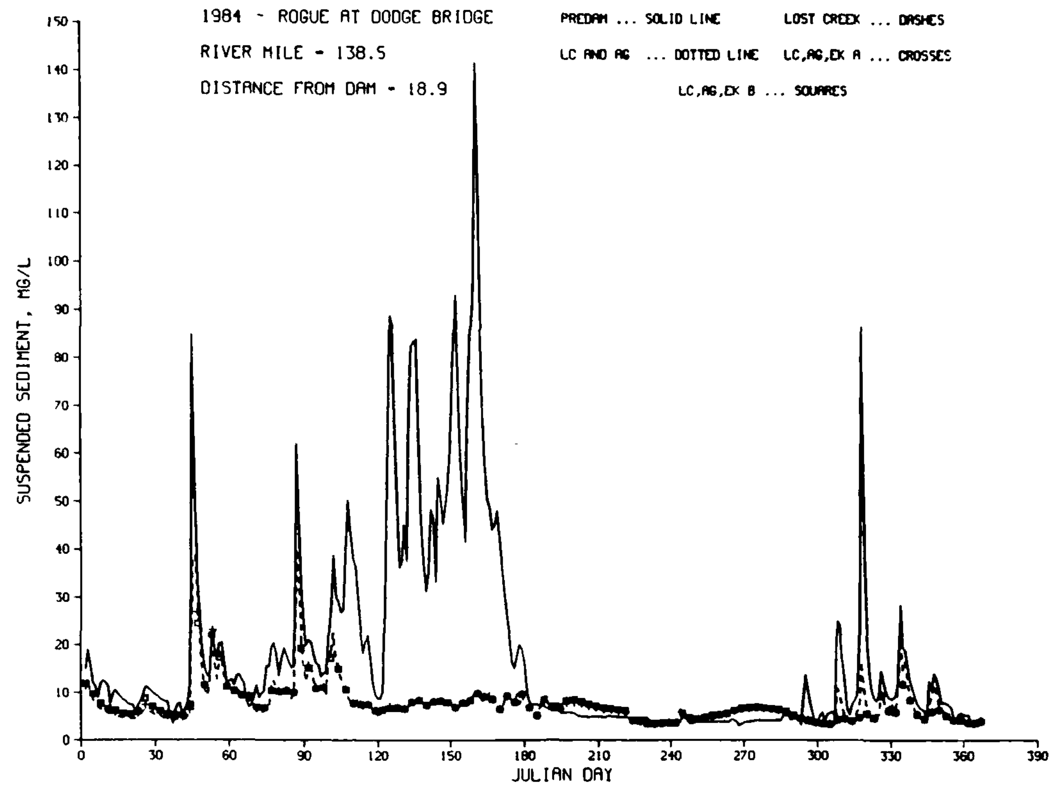


Figure 36. Impact of Elk Creek Dam on Rogue River suspended sediment concentration at the "at Dodge Bridge" station during a wet year

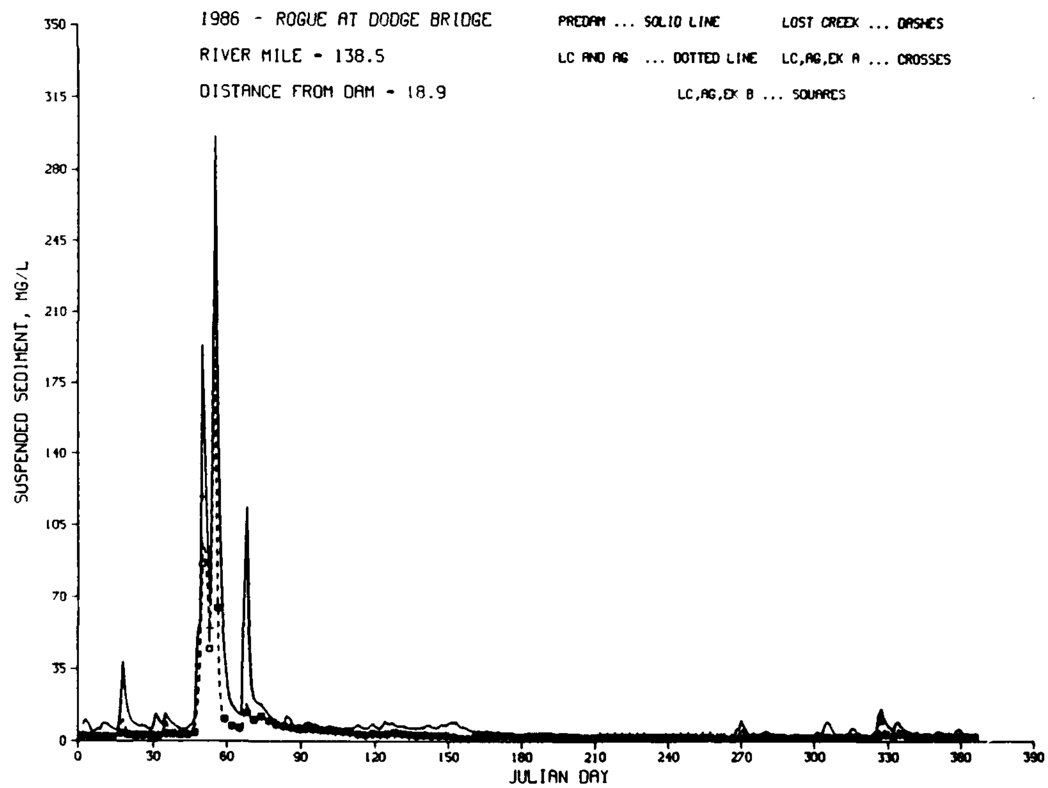


Figure 37. Impact of Elk Creek Dam on Rogue River suspended sediment concentration at the "at Dodge Bridge" station during a normal year

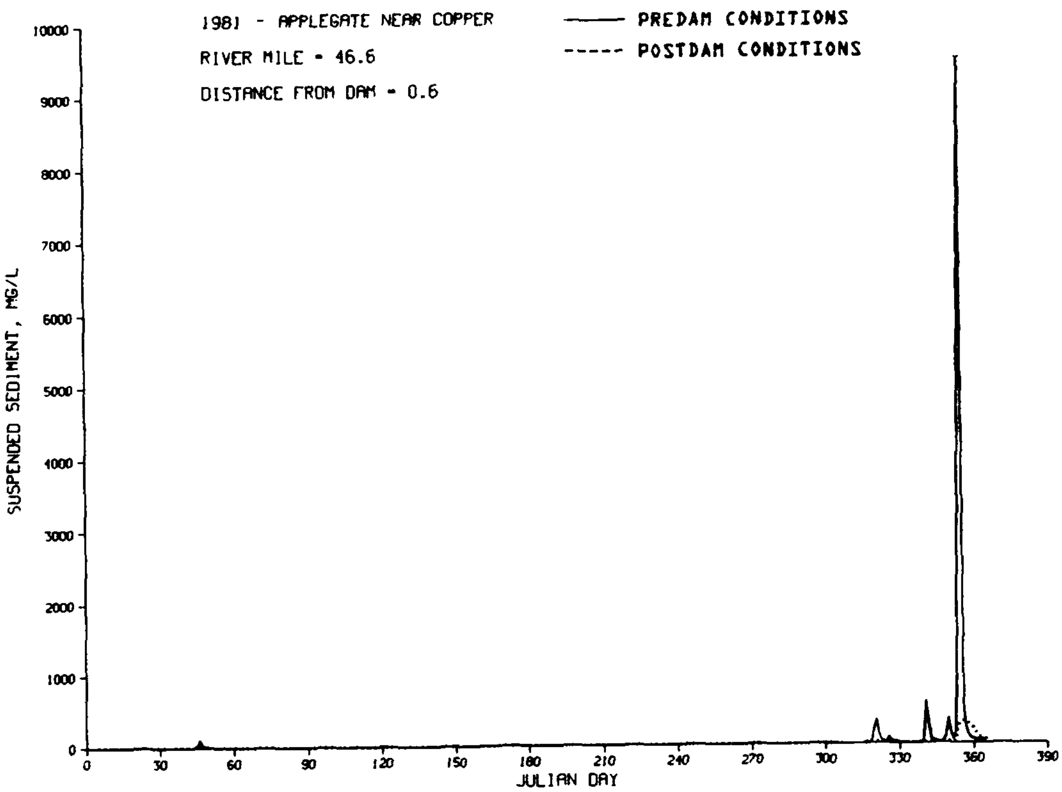


Figure 38. Impact of Applegate Dam on Applegate River suspended sediment concentration in the immediate tailwater during a dry year

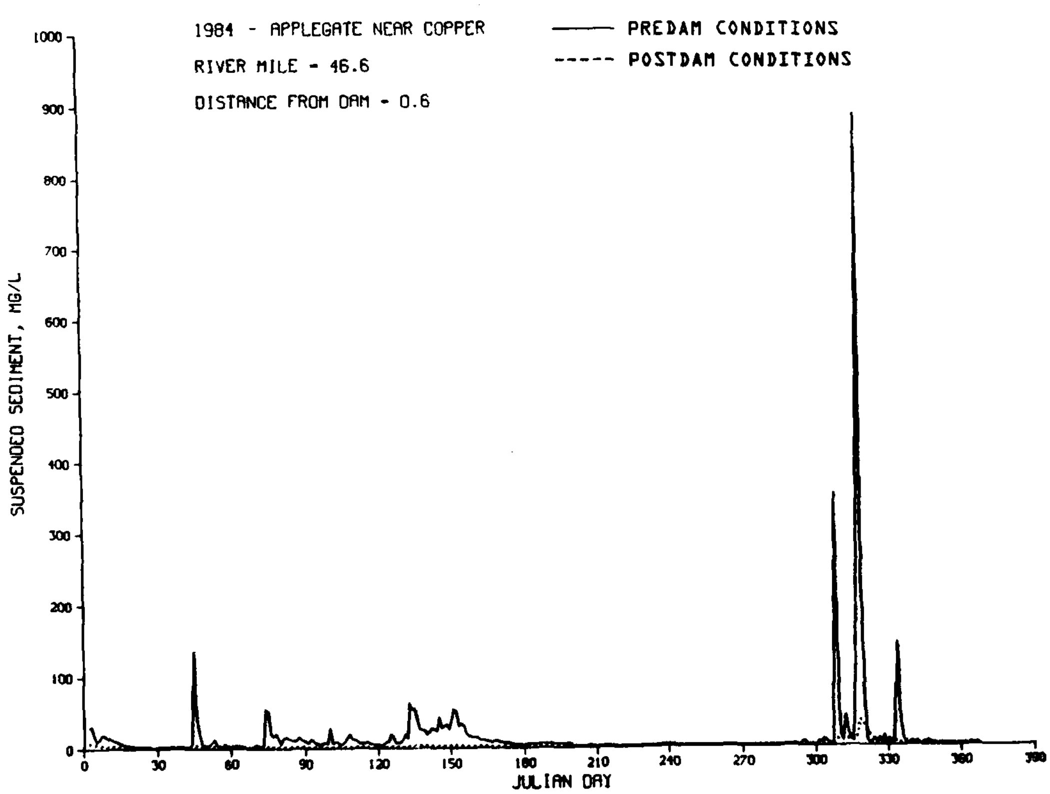


Figure 39. Impact of Applegate Dam on Applegate River suspended sediment concentration in the immediate tailwater during a wet year

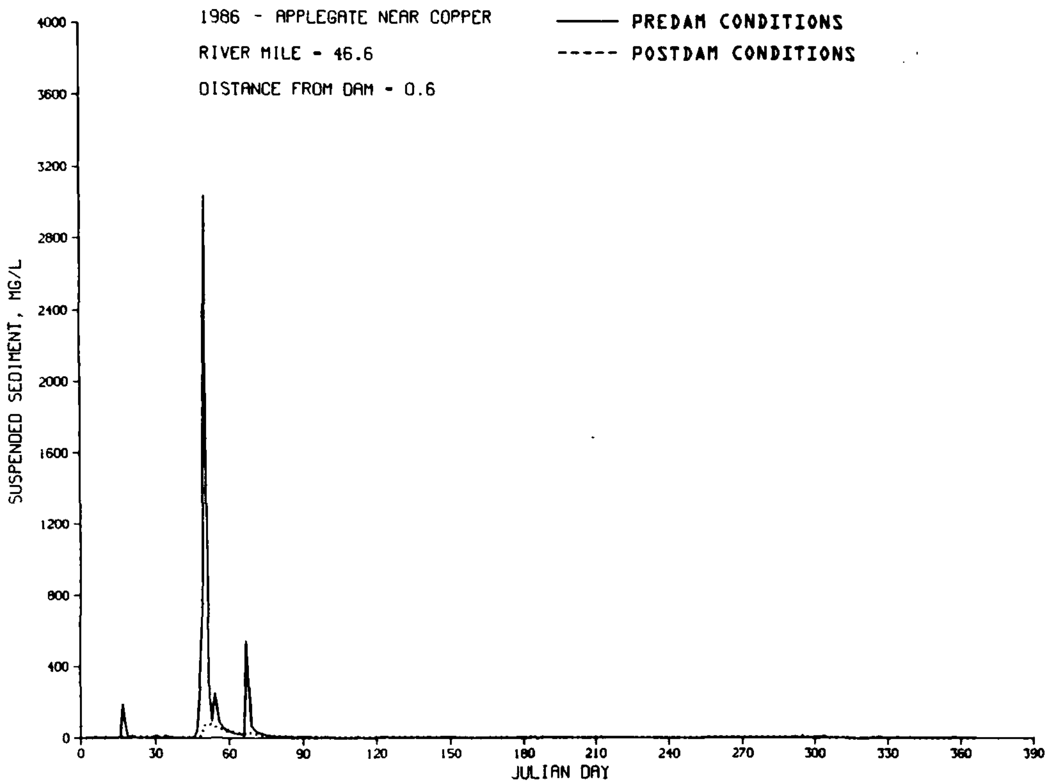


Figure 40. Impact of Applegate Dam on Applegate River suspended sediment concentration in the immediate tailwater during a normal year

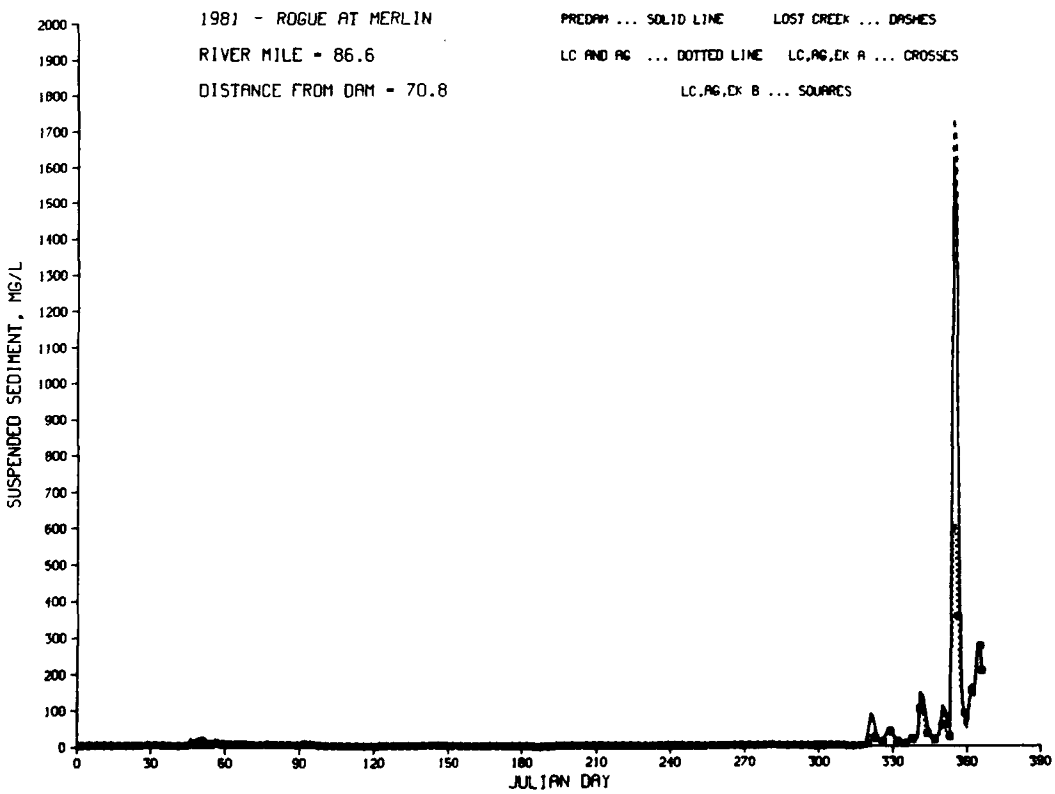


Figure 41. Impact of Applegate Dam on Rogue River suspended sediment concentration at the "at Merlin" station during a dry year

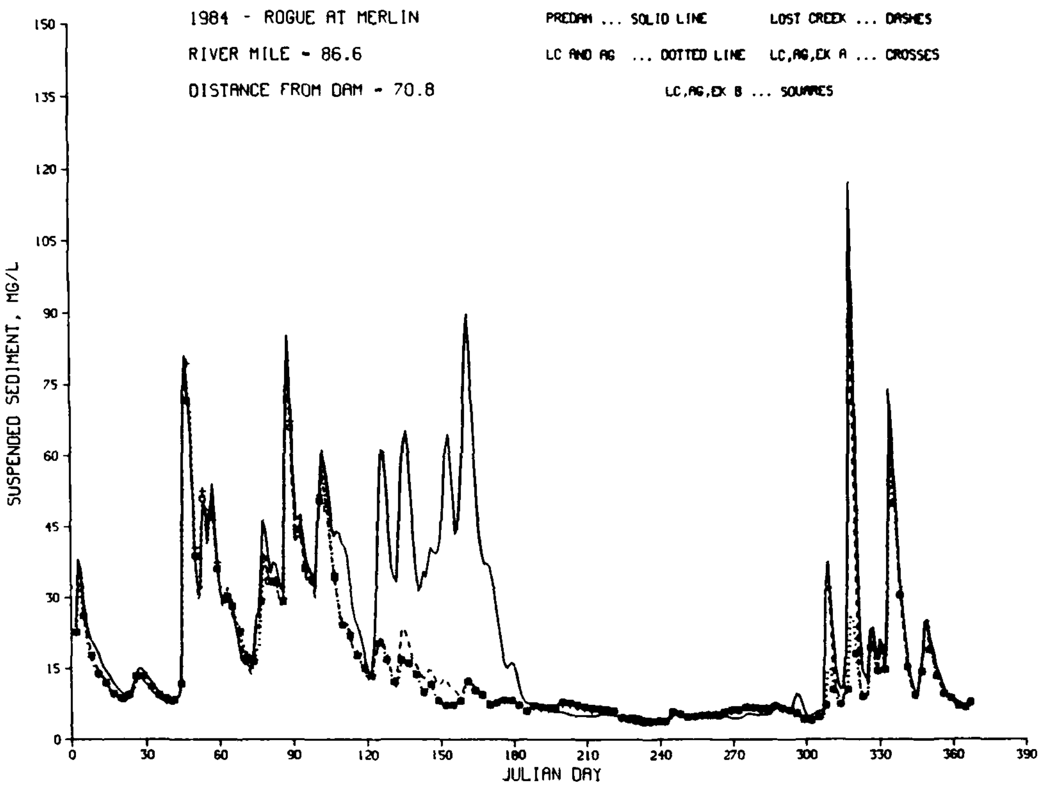


Figure 42. Impact of Applegate Dam on Rogue River suspended sediment concentration at the "at Merlin" station during a wet year

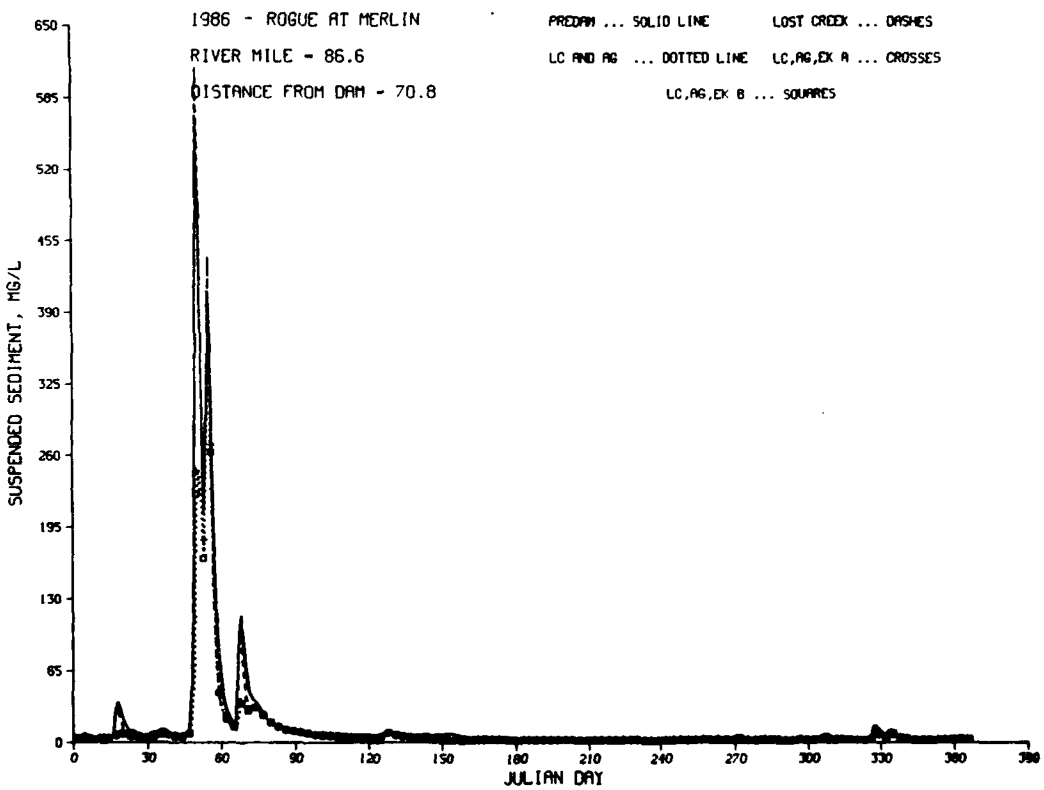
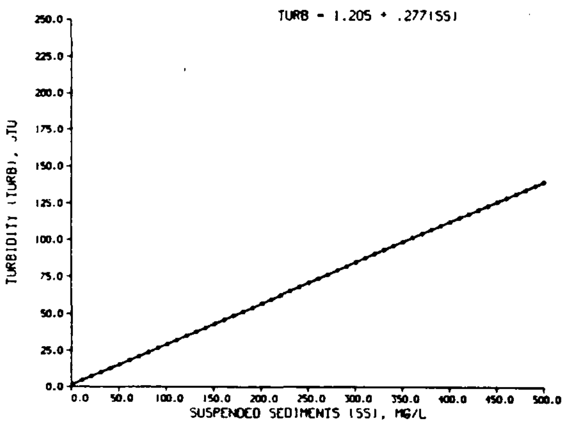
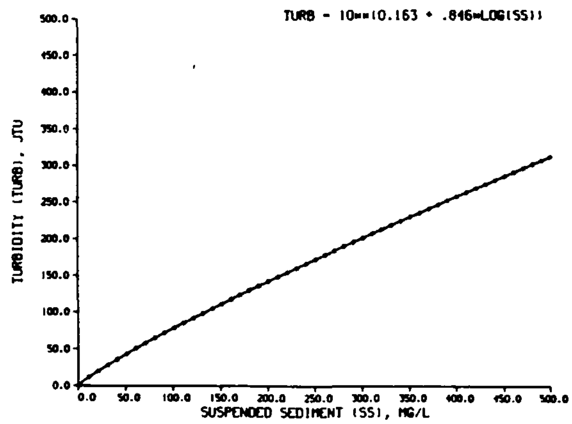


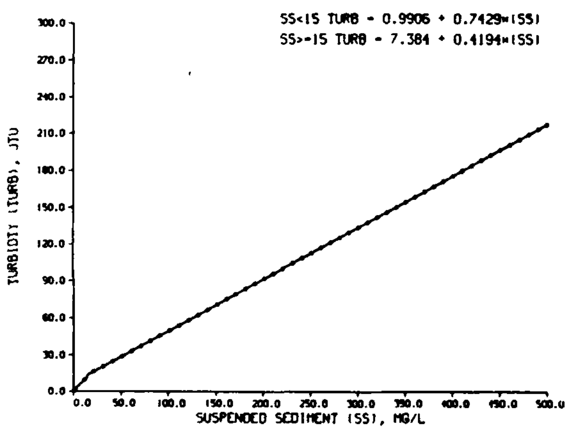
Figure 43. Impact of Applegate Dam on Rogue River suspended sediment concentration at the "at Merlin" station during a normal year



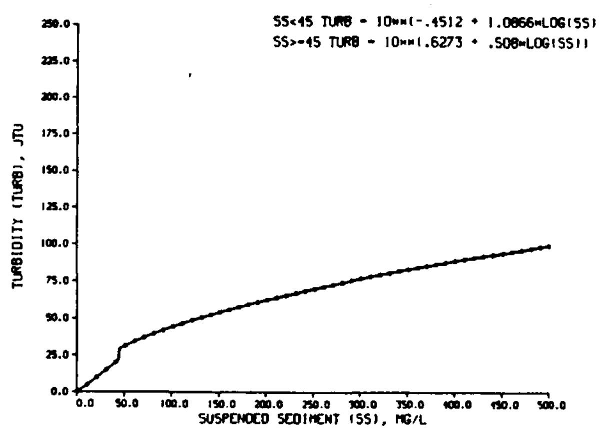
a. "at McLeod"



b. "near Trail"



c. "at Dodge Bridge"



d. "near Copper"

Figure 44. Conversion relationships for turbidity at index stations in the Rogue River Basin

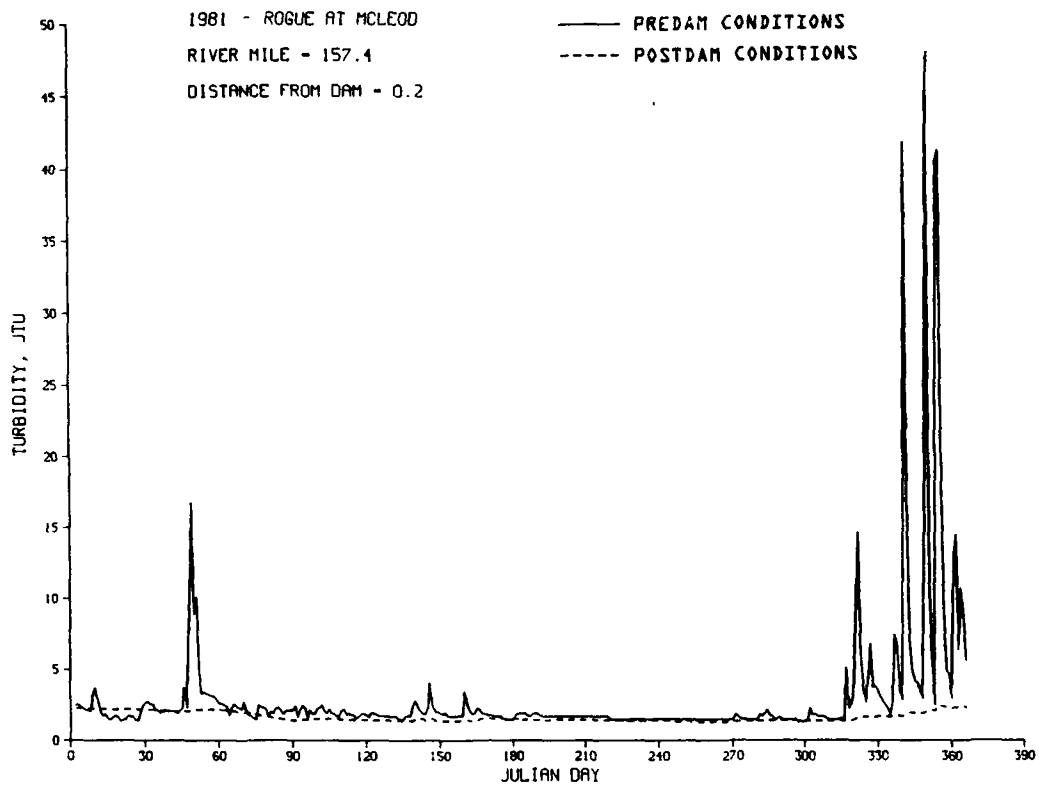


Figure 45. Impact of Lost Creek Dam on Rogue River turbidity in the immediate tailwater during a dry year

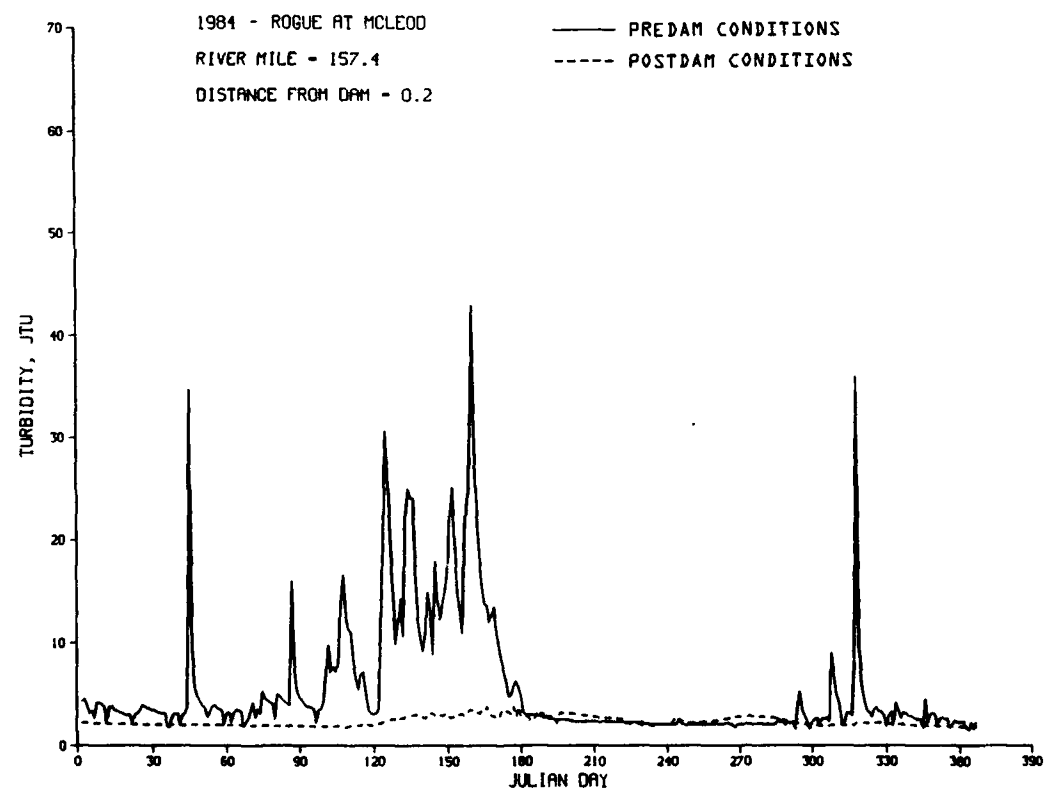


Figure 46. Impact of Lost Creek Dam on Rogue River turbidity in the immediate tailwater during a wet year

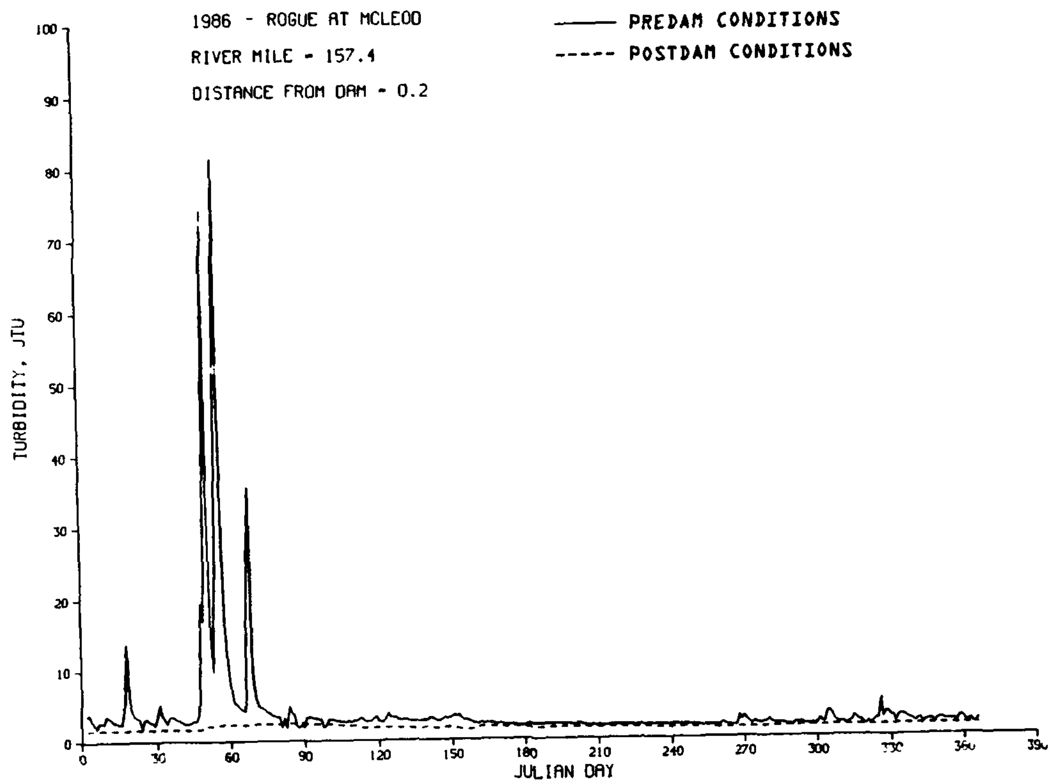


Figure 47. Impact of Lost Creek Dam on Rogue River turbidity in the immediate tailwater during a normal year

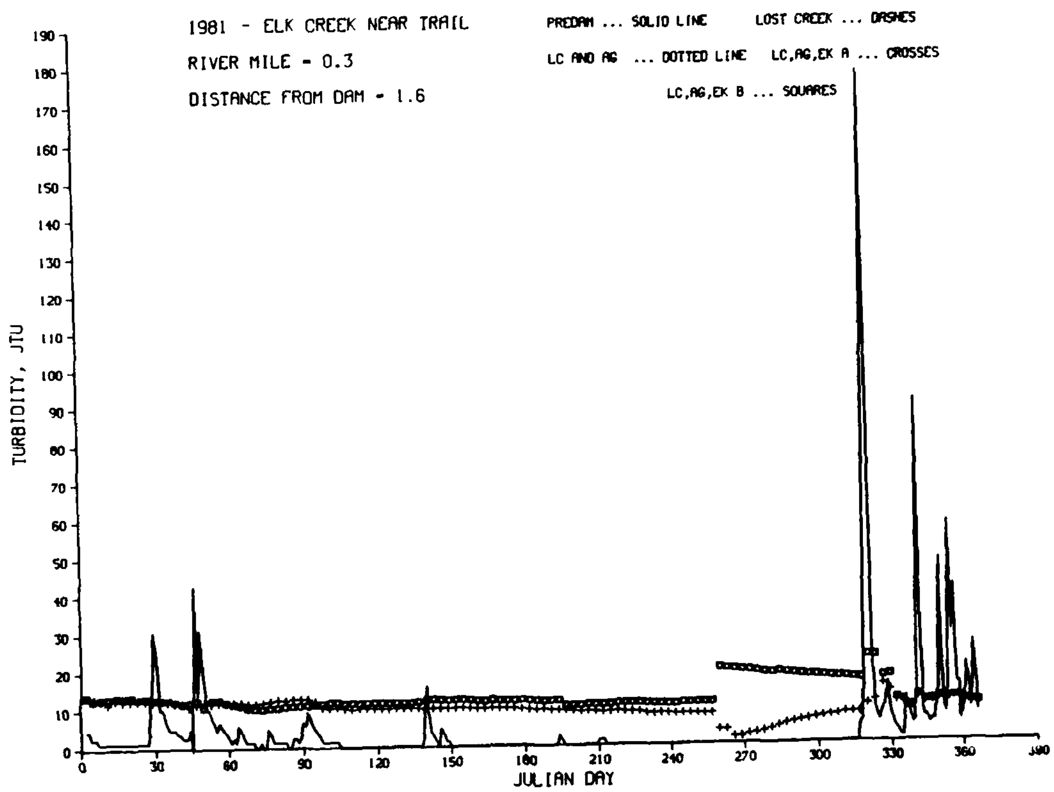


Figure 48. Impact of Elk Creek Dam on Elk Creek turbidity in the immediate tailwater during a dry year

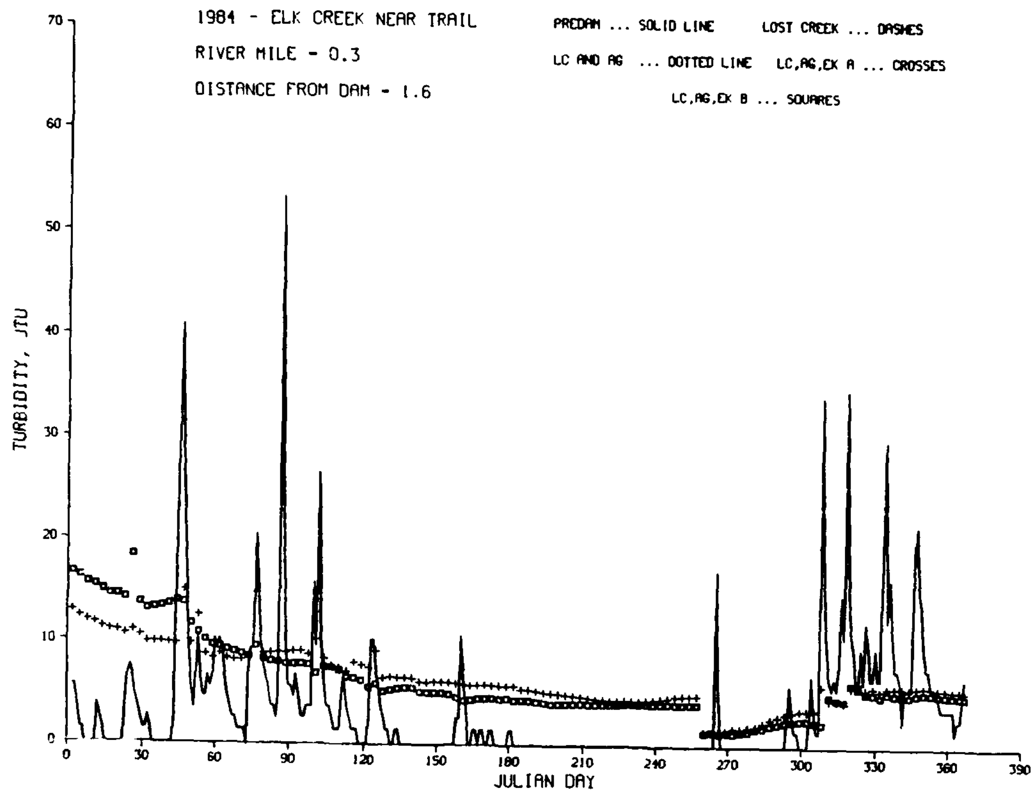


Figure 49. Impact of Elk Creek Dam on Elk Creek turbidity in the immediate tailwater during a dry year

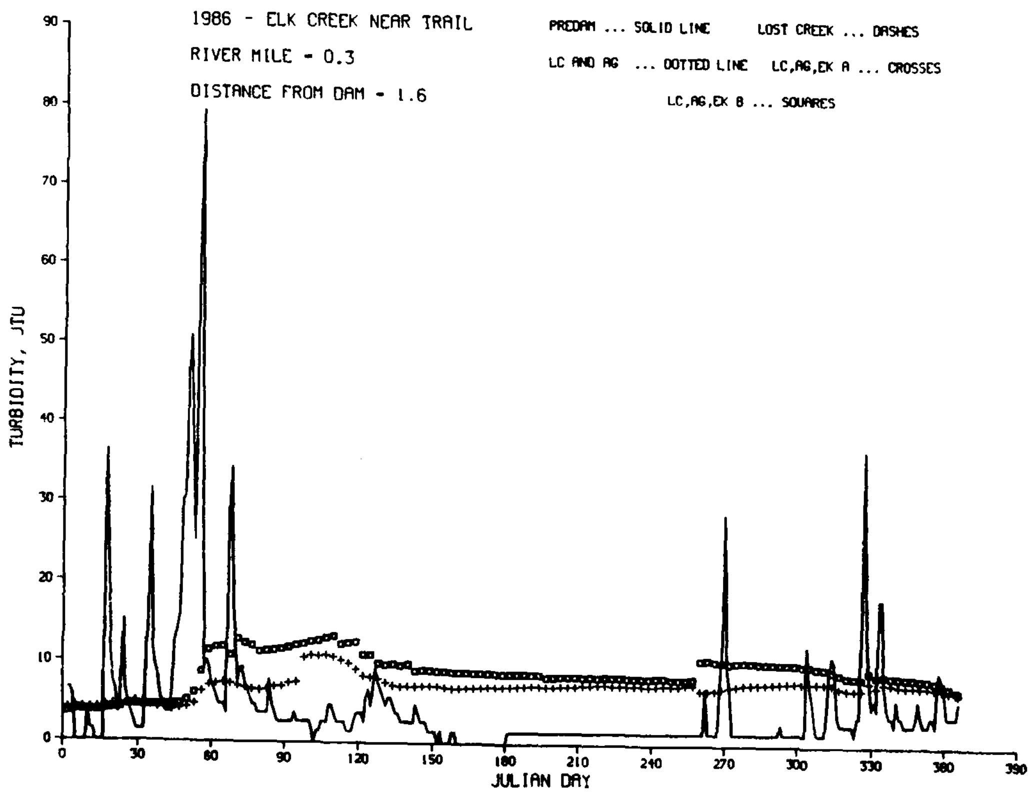


Figure 50. Impact of Elk Creek Dam on Elk Creek turbidity in the immediate tailwater during a dry year

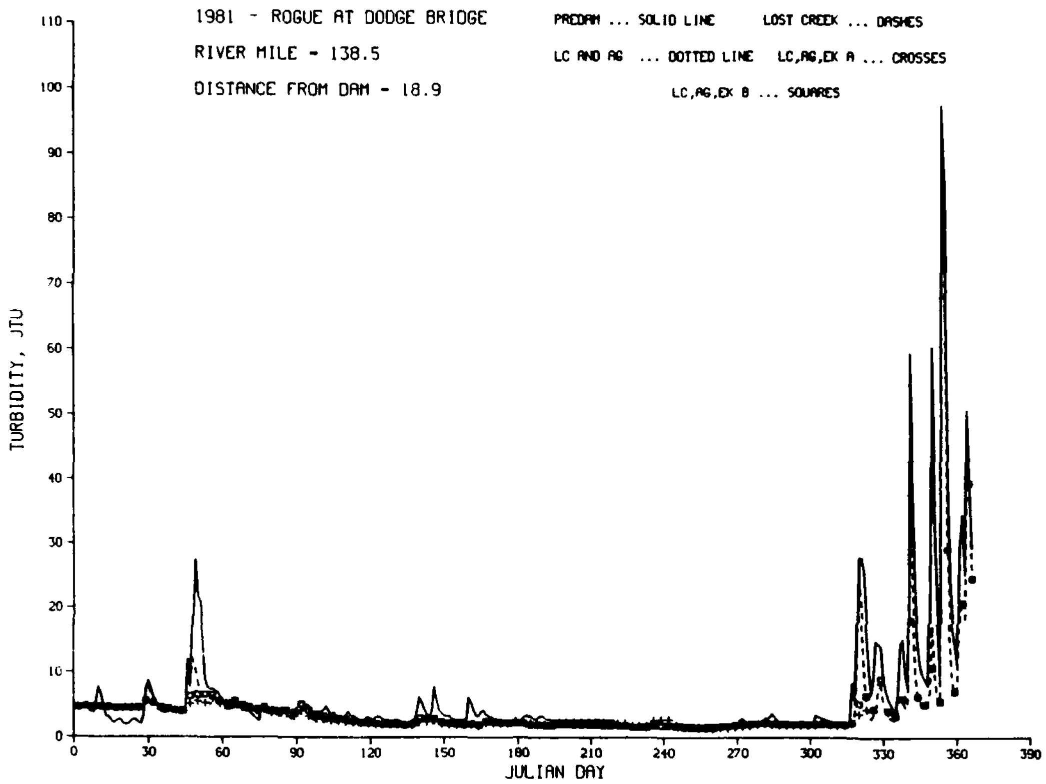


Figure 51. Impact of Elk Creek Dam on Rogue River turbidity at the "at Dodge Bridge" station during a dry year

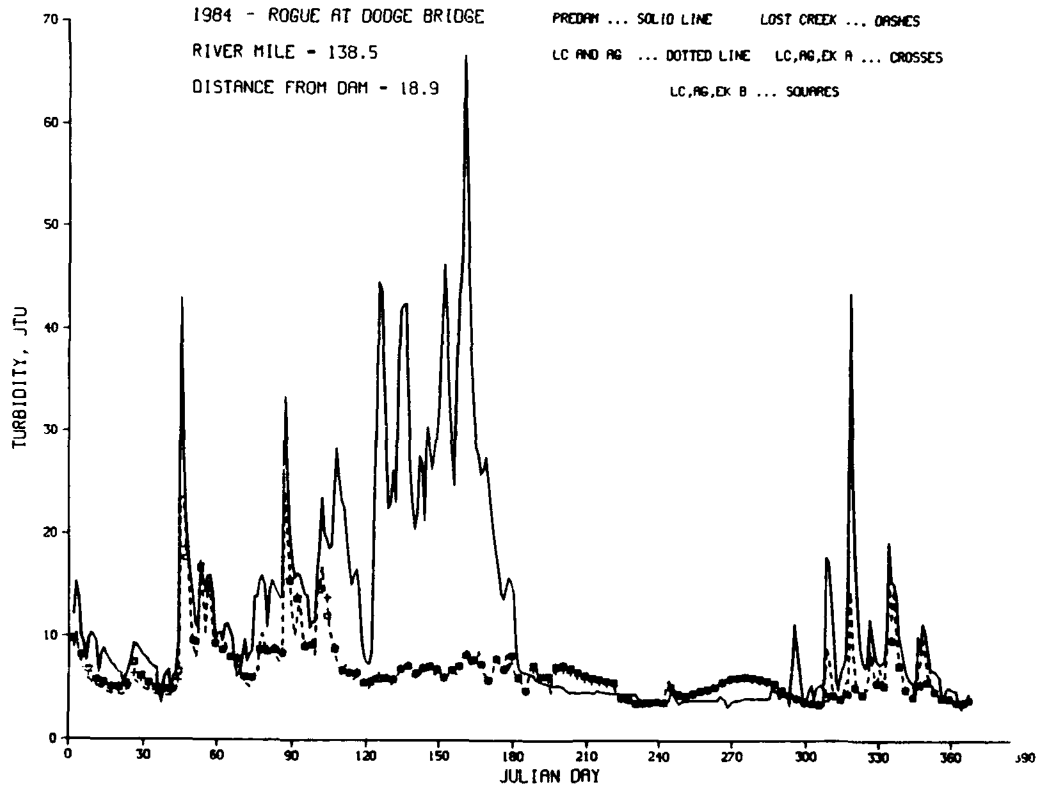


Figure 52. Impact of Elk Creek Dam on Rogue River turbidity at the "at Dodge Bridge" station during a wet year

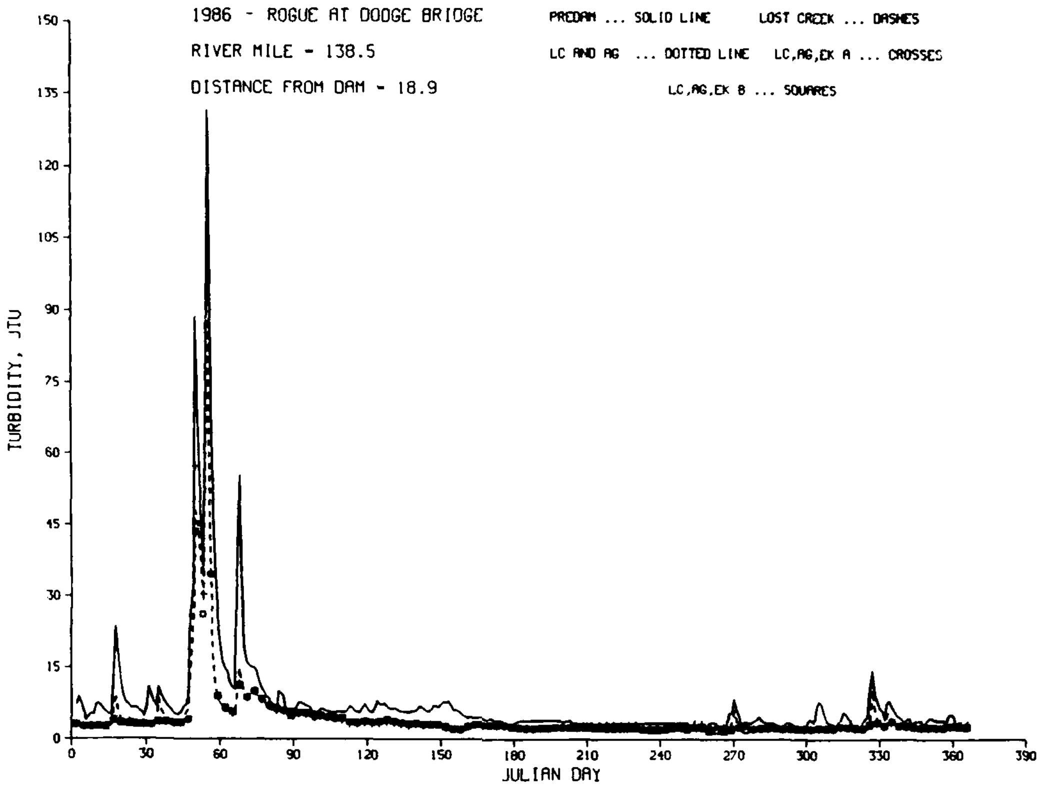


Figure 53. Impact of Elk Creek Dam on Rogue River turbidity at the "at Dodge Bridge" station during a normal year

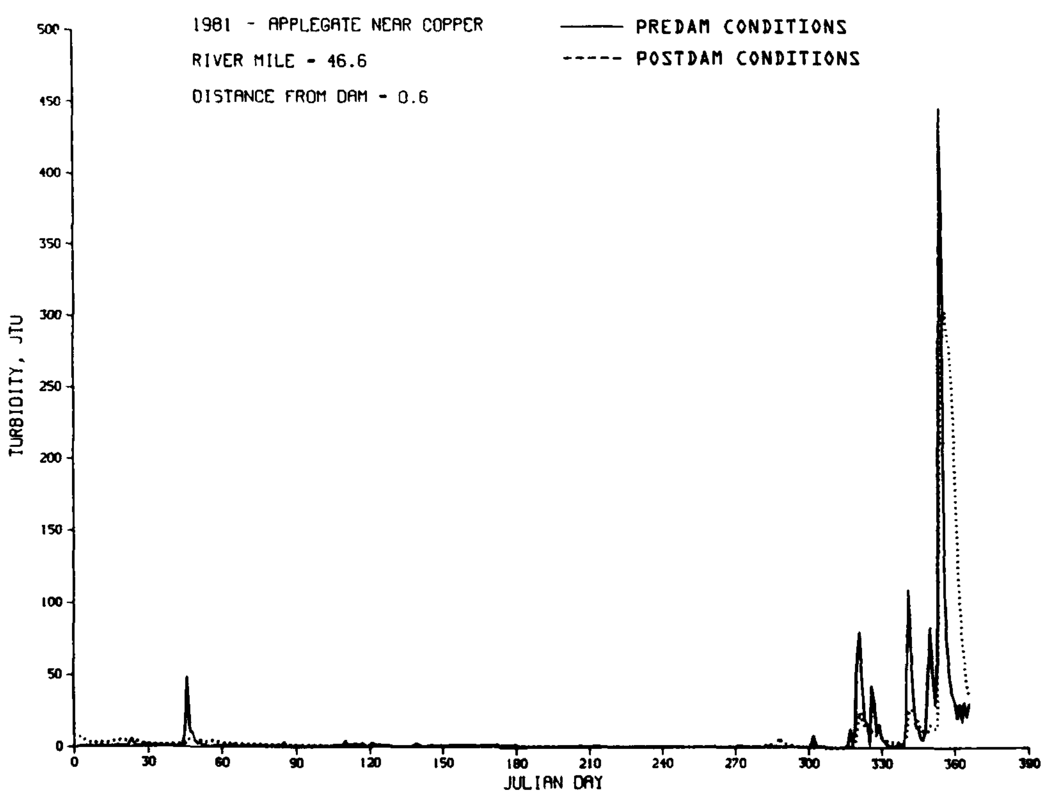


Figure 54. Impact of Applegate Dam on Applegate River turbidity in the immediate tailwater during a dry year

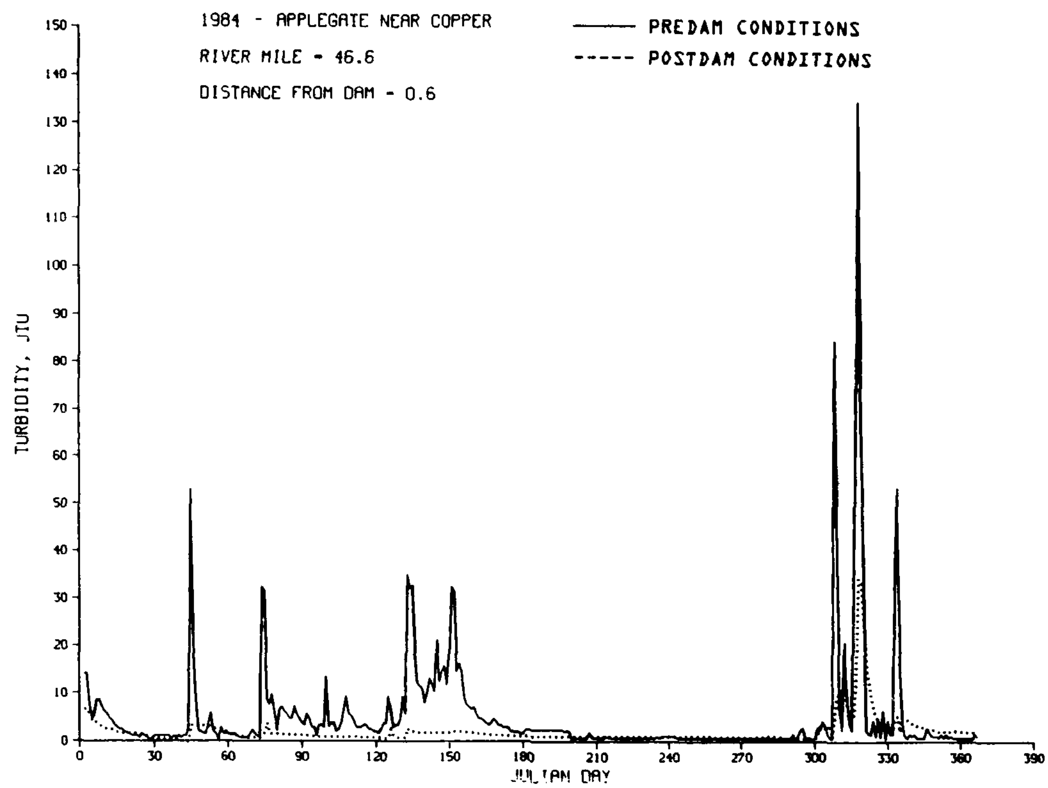


Figure 55. Impact of Applegate Dam on Applegate River turbidity in the immediate tailwater during a wet year

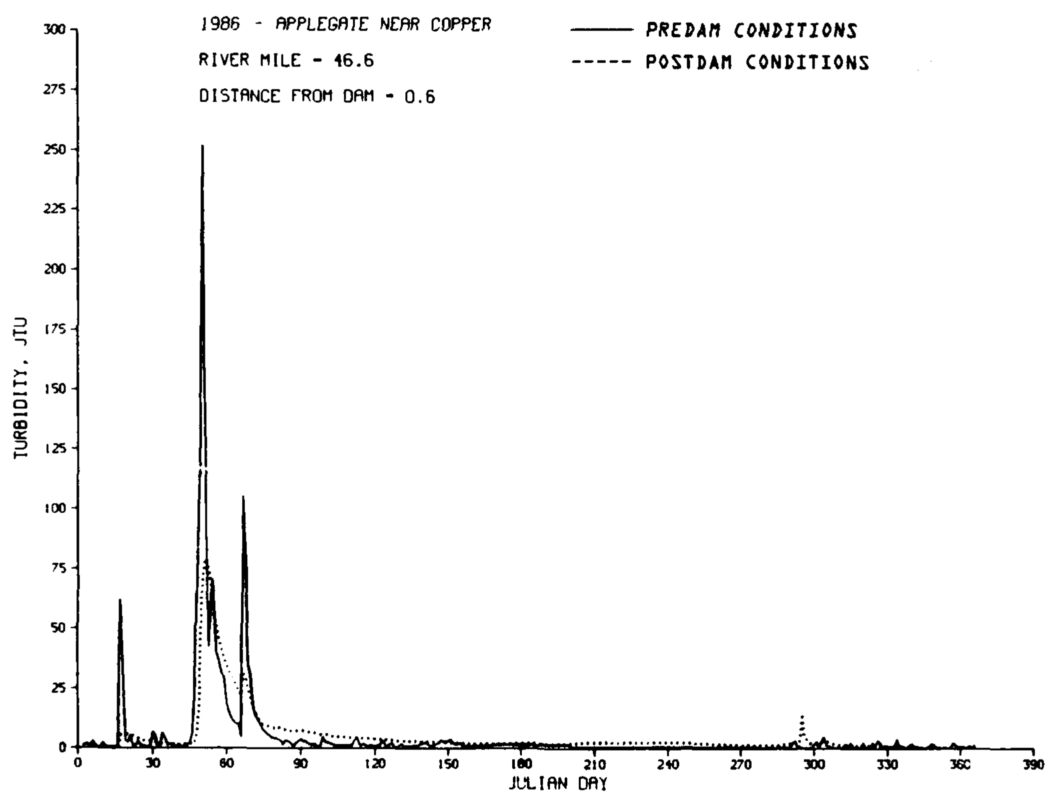


Figure 56. Impact of Applegate Dam on Applegate River turbidity in the immediate tailwater during a normal year

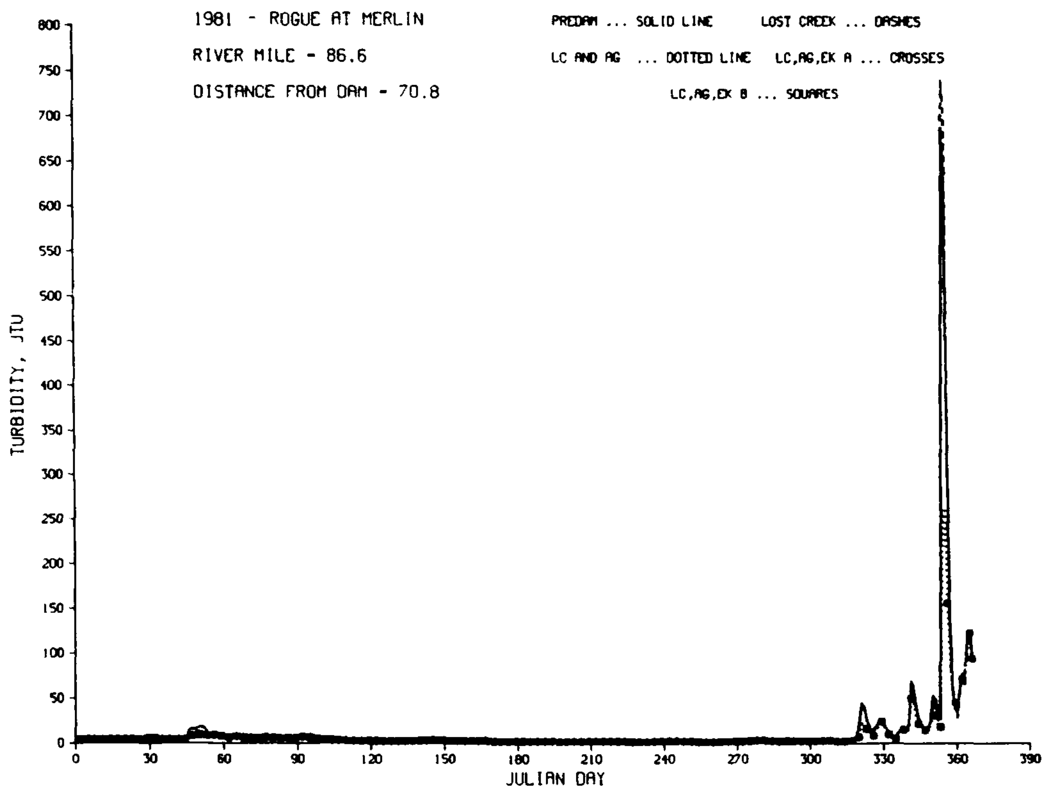


Figure 57. Impact of Applegate Dam on Rogue River turbidity at the "at Merlin" station during a dry year

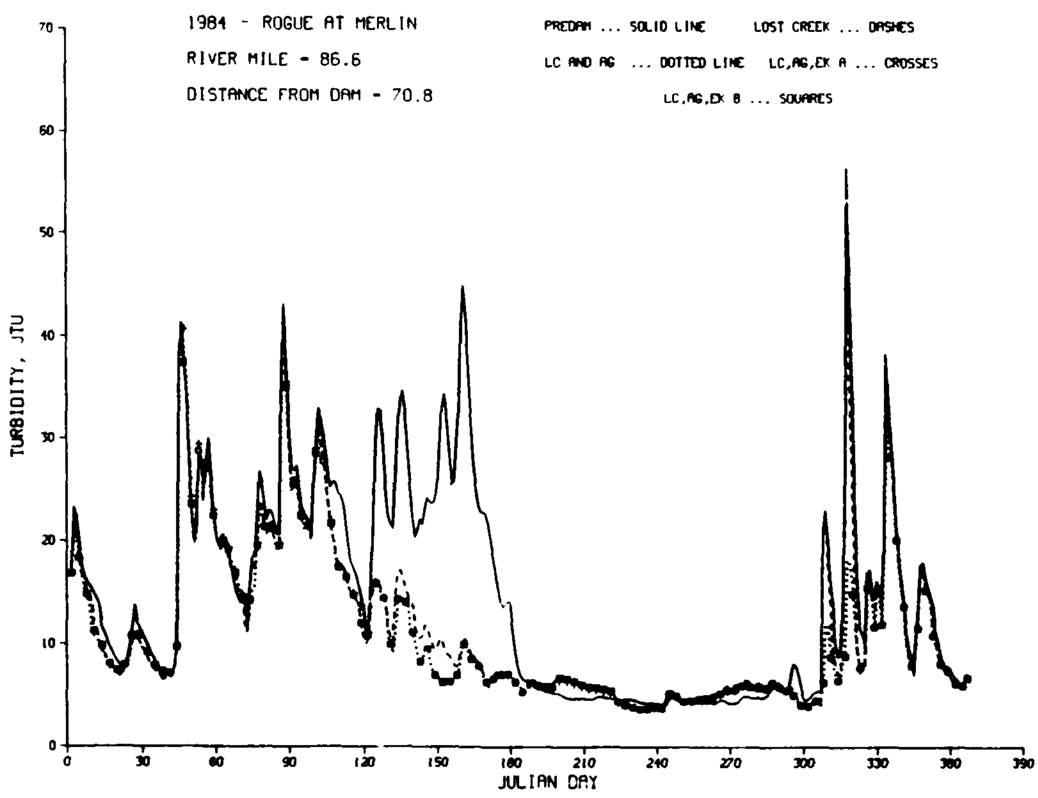


Figure 58. Impact of Applegate Dam on Rogue River turbidity at the "at Merlin" station during a wet year

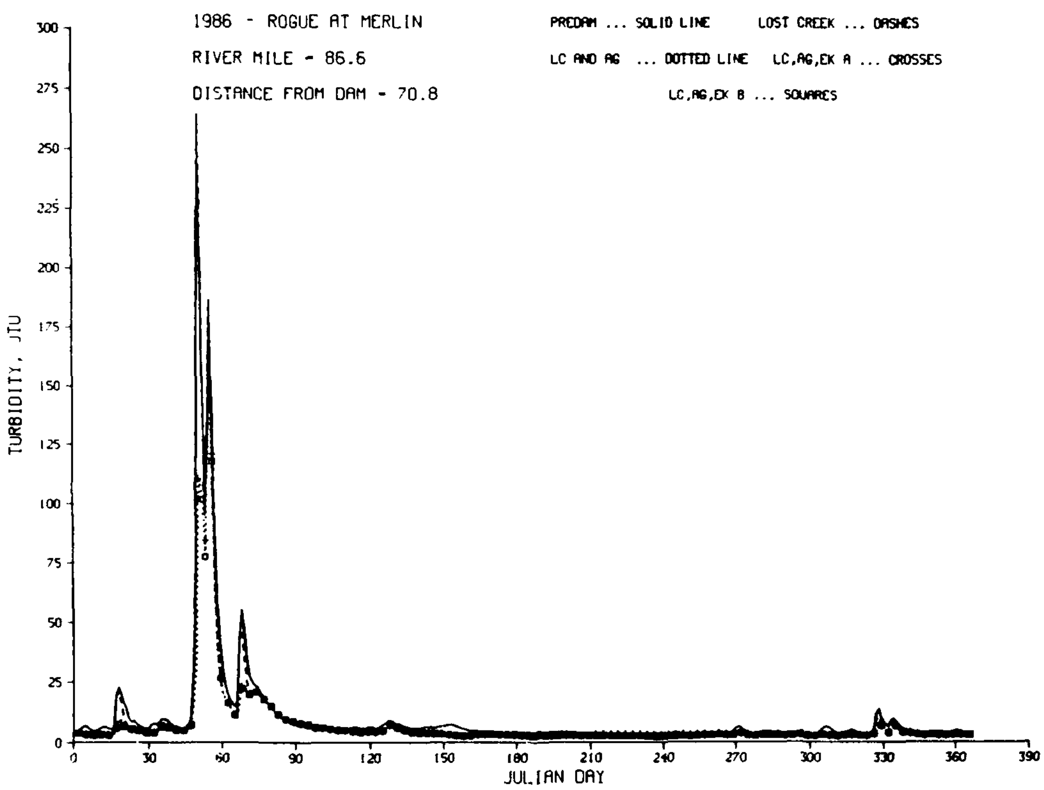


Figure 59. Impact of Applegate Dam on Rogue River turbidity at the "at Merlin" station during a normal year